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U.S. RESEARCH SAFETY VEHICLE (RSV) PHASE I PROGRAM- VOLUME III, RSV CHARACTERISTICS AND PERFORMANCE SPECIFICATIONS

Contract No. DOT-HS-4-00841
June 1975
Final Report

PREPARED FOR:

U.S. DEPARTMENT OF TRANSPORTATION

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

WASHINGTON, D.C. 20590

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Prepared for the Department of Transportation, National Highway Traffic Safety Administration under Contract No. DOT-HS-4-00841. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the National Highway Traffic Safety Administration.

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Technical Report Documentation Page

1. Report No. DOT HS-801 596	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle U.S. RESEARCH SAFETY VEHICLE (RSV) PHASE I PROGRAM. - ~~Volume III, RSV Characteristics and Performance Specifications~~ V.3.		5. Report Date June 1975
		6. Performing Organization Code
7. Author(s) J. Andon, E. Dodson, A. Khadilkar, R. Olson, L. Pauls, and W. Rup.		8. Performing Organization Report No. ASL-B31
9. Performing Organization Name and Address ~~AMF Incorporated~~ Advanced Systems Laboratory 495 South Fairview Avenue Goleta, California 93017		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DOT-HS-4-00841
12. Sponsoring Agency Name and Address U.S. Department of Transportation National Highway Traffic Safety Administration 400 Seventh Street, S.W. Washington, D.C. 20590		13. Type of Report and Period Covered FINAL REPORT Jan. 1974-April 1975
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Current passenger car usage patterns and factors influencing usage are analyzed and projections of usage patterns in the mid-1980's are made. Similarly, current available data on six categories of vehicle accidents are analyzed and projections made of national accident patterns in the mid-80's; the effect of potential reductions in these projections as a result of safety programs and other factors related to driving safety are estimated.

Based on the usage and accident projections, the characteristics of an RSV (weighing under 3,000 lbs C.W.) for operation in the mid-1980 traffic environment are described.

A recommended set of specifications for the RSV are developed considering the potential safety payoff accruing to an increased level of safety performance, the need for energy conservation, availability of material resources, and changes in vehicle mix.

An executive summary of this report is presented in Volume I.

17. Key Words Passenger car usage Vehicle accidents Projections of accidents in 1985 RSV specifications	18. Distribution Statement Unlimited. Available through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	367	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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VOLUME III

TABLE OF CONTENTS

		Page
SECTION 4 - VEHICLE CHARACTERIZATION		
4.0	INTRODUCTION	4-1
4.1	VEHICLE CONFIGURATION	4-3
4.1.1	4-Passenger RSV Sedan	4-3
4.1.2	2-Passenger RSV Sedan	4-9
4.2	SAFETY PERFORMANCE CHARACTERISTICS	4-13
4.2.1	Visibility, Lighting, and Signaling	4-13
4.2.2	Riding and Handling Systems	4-16
	RSV System	4-16
	Braking System	4-19
	Steering System	4-23
	Handling Response	4-27
	Overturning Immunity	4-29
	Front and Rear Suspension Systems	4-29
	Wheels and Tires	4-33
4.2.3	Crashworthiness	4-34
	Vehicle Interior	4-37
	Vehicle Body Structure	4-39
	Vehicle Body Exterior	4-41
	Occupant Restraints	4-42
4.3	FUNCTIONAL PERFORMANCE CHARACTERISTICS	4-43
4.3.1	Propulsion (Power Train) System	4-43
4.3.2	Accessories	4-48
4.4	SUPPORTING RATIONALE	4-49
4.4.1	Visibility, Lighting, and Signaling	4-49

VOLUME III

TABLE OF CONTENTS (Cont'd)

		Page
4.4.2	Riding and Handling Systems	4-52
	Causal Factors	4-52
	Characterization Guidelines	4-58
	Specific Characteristics	4-59
4.4.3	Crashworthiness	4-60
	Vehicle Interior	4-60
	Vehicle Body Structure	4-65
	Vehicle Body Exterior	4-65
	Occupant Restraints	4-70
4.4.4	Propulsion System	4-72
	Current System Characterization	4-72
	Fuel Economy and Driving Range	4-74
	Propulsion System State of the Art	4-75
4.4.5	Accessories	4-85
4.5	USE OF RSV CHARACTERIZATIONS	4-85

SECTION 5 - RSV TECHNICAL PERFORMANCE SPECIFICATIONS

5.0	INTRODUCTION		5-1
5.1	PERFORMANCE SPECIFICATIONS	Section 5.1	
5.2	SUPPORTING RATIONALE		Section 5.2
	TECHNICAL SPECIFICATION U.S. RESEARCH SAFETY VEHICLE (RSV)		
1.0	GENERAL DESIGN REQUIREMENTS	5-4	5-46
1.1	OBJECTIVES	5-4	5-46
1.2	VEHICLE DESCRIPTION	5-5	5-46
2.0	SAFETY PERFORMANCE REQUIREMENTS	5-6	5-48
2.1	VEHICLE HANDLING AND STABILITY SYSTEMS	5-6	5-49

VOLUME III

TABLE OF CONTENTS (Cont'd)

		Section 5.1	Section 5.2
2.1.1	Braking Performance	5-7	5-49
2.1.2	Steering	5-11	5-66
2.1.3	Handling	5-16	5-78
2.1.4	Overturning Immunity	5-18	5-89
2.1.5	Power Plant System	5-20	5-91
2.1.6	Ride Performance	5-21	5-95
2.2	VISIBILITY SYSTEMS	5-21	5-96
2.2.1	Driver Visibility	5-21	5-96
2.2.2	Lighting	5-24	5-98
2.3	DRIVER ENVIRONMENT SYSTEMS	5-26	5-100
2.3.1	Controls and Displays	5-26	5-100
2.3.2	Warning Devices	5-27	5-100
2.3.3	Environment	5-27	5-101
2.3.4	Emergency Equipment	5-28	5-102
2.4	CRASH ENERGY MANAGEMENT SYSTEMS	5-28	5-103
2.4.1	Structural Systems	5-29	5-131
2.4.1.1	Front Structure	5-31	5-156
2.4.1.2	Side Structure	5-33	5-164
2.4.1.3	Roof Structure	5-33	5-164
2.4.1.4	Rear Structure	5-33	5-165
2.4.2	Exterior Protection	5-34	5-175
2.4.3	Fuel System Integrity	5-34	5-175
2.4.4	Pedestrian/Cyclist Protection	5-34	5-176
2.4.4.1	Vehicle Design Requirements	5-34	
2.4.4.2	Vehicle Design Goals	5-37	
2.5	OCCUPANT COMPARTMENT SYSTEMS	5-37	5-180
2.5.1	Seating Systems	5-37	5-183

VOLUME III

TABLE OF CONTENTS (Cont'd)

		Section 5.1	Section 5.2
2.5.2	Occupant Restraint Systems	5-39	5-185
2.5.3	Flammability	5-41	5-201
2.5.4	Interior Design	5-41	5-201
2.5.5	Emergency Egress	5-42	5-203
3.0	VEHICLE SYSTEMS REQUIREMENTS	5-42	5-206
3.1	POWER PLANT, FUEL, COOLING AND EXHAUST SYSTEMS	5-42	5-206
3.2	TIRE AND WHEEL SYSTEMS	5-43	5-207
3.3	ELECTRICAL SYSTEM	5-43	5-210
3.4	INTERIOR COMFORT	5-44	5-210
3.5	MAINTENANCE	5-44	5-210
4.0	PRODUCIBILITY	5-44	5-210
4.1	MATERIALS AND APPLICATIONS	5-44	
4.2	COMPONENTS AND SUBSYSTEMS	5-45	
4.3	PROTOTYPE RSV	5-45	
5.0	APPLICABLE DOCUMENTS	5-45	5-214

SECTION 4
VEHICLE CHARACTERIZATION

4.0 INTRODUCTION

Based on the projections of the usage and accident environments presented in Sections 3.1 and 3.2 of this report, a set of characteristics describing a Research Safety Vehicle was developed. As noted in the usage projections, no discrete subenvironments were identified for vehicles operating in the mid-80's. Rather, it is anticipated that vehicle designs will continue to follow the evolutionary patterns and trends experienced in the past. The rate of design evolution, however, is expected to accelerate to meet increasing demands for energy conservation. Therefore, RSV characterizations are influenced primarily by usage and marketing considerations and not by unique or different environments.

The maximum weight of 3,000 pounds for the RSV imposes a number of physical constraints on its design (the number of occupants, overall dimensions, engine size, luggage space, etc.). However, these constraints do not preclude the development of an acceptable and producible RSV which may ultimately prove to be more compatible with the total environmental and resource limitations in the mid-80's than would the larger cars. Usage projections indicate that a 4-passenger sedan would adequately satisfy the average occupancy needs for all identified travel purposes. Therefore, one RSV concept is characterized to fulfill this usage. It is recognized that while population forecasts indicate a continuing decline in the size of the average household, there will be families whose size exceeds the average; the car requirements to satisfy these needs can be fulfilled by the mid-80 car models in the weight classes above 3,000 pounds.

Usage forecasts indicate a continuation of the current trend toward low occupancy, short trip length use for a significant percentage of

work-related and family business travel. This suggests that a potential market will exist for a small, utility car whose primary function would be to satisfy this usage in a more economical manner than would the 4-passenger RSV concept or the larger cars. This consideration led to the characterization of a second RSV concept, a 2-passenger utility car.

In effect, usage projections and considerations imply a continuation of the present multi-car household patterns, with the single car household choosing the larger car to fulfill all trip purposes. There are no indications that the drivers of the second (or third) car restrict its use in any way, consequently, the second RSV concept of the utility car will be exposed to the same traffic and accident environment as is the first concept.

The subsequent parts of this section present the characterization descriptors of both concepts where required, and common descriptors where RSV size is not a factor. To the extent possible, characterization is associated with need as determined from current assessments and projections, primarily with those associated with the accident environment. State of the art considerations are treated in terms of the mid-80's, where such developments can be anticipated as a result of current work. In many instances, a number of alternative approaches can satisfy the characterization of specific RSV subsystems; the alternatives are listed with a final selection to be made by the car designer.

Where quantitative descriptions are used in characterization, these are considered to be first approximations based on current passenger car designs and performance and on engineering estimates. Similarly, some characterization descriptions are equivalent to specifications; a clear distinction between the two is always evident. In all cases, descriptors, in either quantitative or qualitative terms, are subject to change when future design analyses will provide a valid basis for establishing firm values.

4.1 VEHICLE CONFIGURATION

Two RSV concepts are characterized based on projected usage considerations, one concept is based on a 4-passenger family sedan, and the second, on a 2-passenger utility sedan. For each concept, a number of variations in configuration are possible and these are described in terms of their relative merits.

4.1.1 4-Passenger RSV Sedan

The external configuration of this concept is shown in Figure 4-1, as a 2-door sedan to accommodate two 95th percentile males in the front seats and two 50th percentile males or three children in the rear seat. The basic dimensions shown in the figure for this concept are based on a front engine, front wheel drive power train arrangement. Conceptual styling lines were based on characterization considerations of minimizing air drag, reducing frontal hazards to pedestrians and bicyclists, providing acceptable sight lines, as well as eye appeal.

Figure 4-2 depicts the internal arrangement of the driver and adult passenger and the volume allocations for the riding and handling systems. Driver seating, controls and displays, visual aids, and restraints are to accommodate the range from a 5th percentile female to a 95th percentile male; as an objective, equal performance of all these subsystems for the range of drivers is sought. The driver position shown in Figure 4-2 is that of a 95th percentile male with a conventional hand and foot control arrangement and an adjustable seat to accommodate the 5th percentile female and improve access to the rear seat entry and exit. This arrangement has limitations in terms of providing equal sight lines and positioning of hand and feet on controls for the driver size range. An alternative arrangement would have movable hand and foot controls and a vertically adjustable seat to enable the drivers to position themselves for the maximum field of view and preferred control positions. With driver seat adjustment limited to vertical movement, access to the rear seat from the driver's door may be limited.

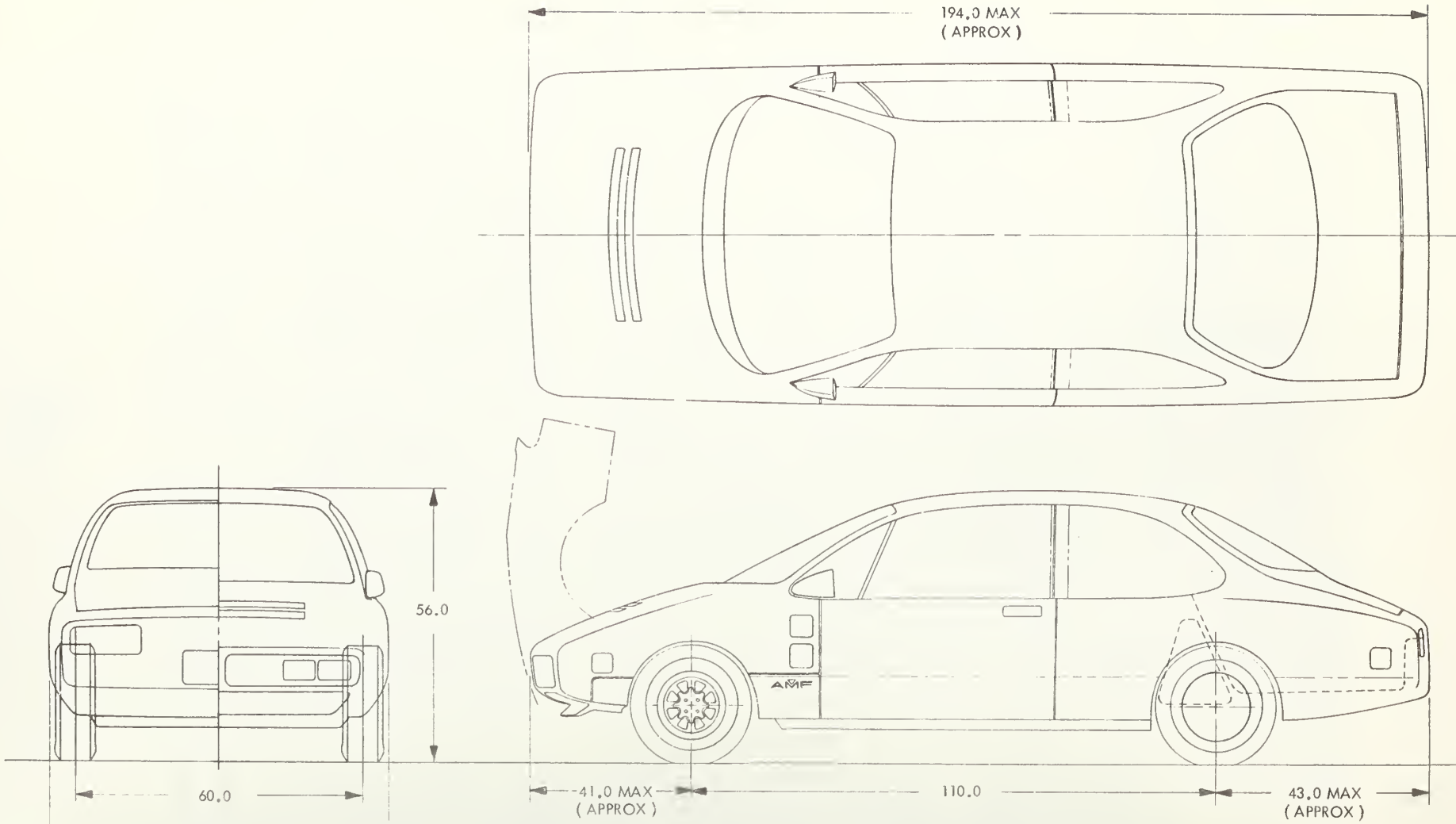


Figure 4-1. Four Passenger RSV Sedan - External Configuration (Front Engine)

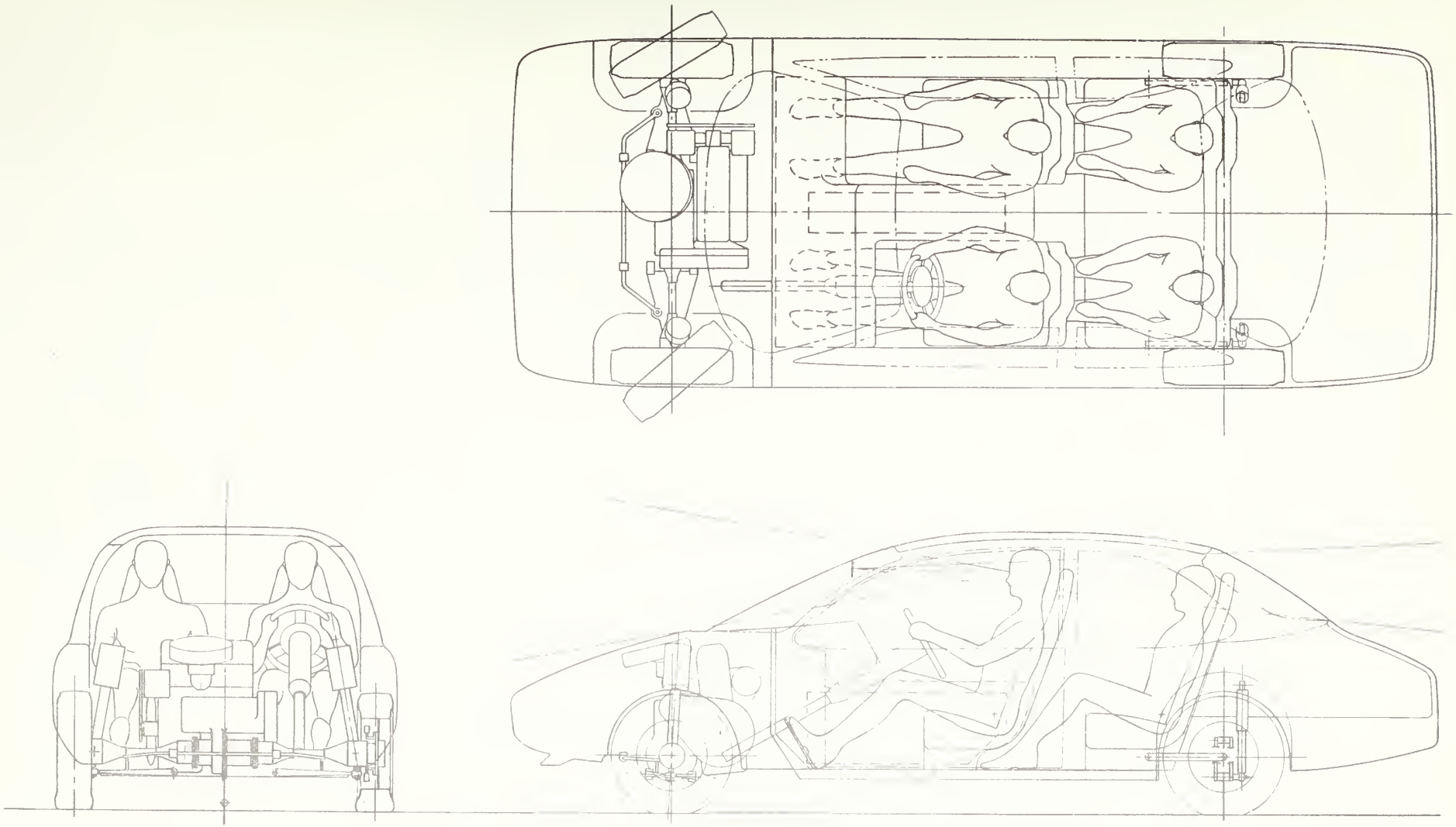


Figure 4-2. Four Passenger RSV Sedan - Internal Configuration

The interior arrangement of front seat area is designed to provide a maximum of occupant ride-down distance for effective performance of any selected restraint system and protective padding. A center console is placed between the front seats to provide an additional area for control or accessory placement and for lateral restraint. The longitudinal length of the console provides a potential location for the fuel tank in an area where structural integrity should be high under all crash modes. A conventional instrument panel layout is anticipated, enhanced by the incorporation of a diagnostic warning system for safety critical functions (e.g., brakes, tires).

Figure 4-3 depicts another external arrangement of a 4-passenger RSV driven by a rear engine, rear wheel drive. The internal arrangement, shown in Figure 4-4, preserves the driver and occupant features provided in the front engine, front wheel drive concept. The characterization considerations for both drive arrangements in terms of general external and internal configurations are essentially the same. The merit of the rear engine concept lies in the relatively free uncluttered front end volume for maximizing energy absorbing performance in frontal impacts.

The curb weight of either concept will be limited to 2,500 to 3,000 pounds range; a feasible weight range for an RSV based on the ESV's developed by off-shore manufacturers. Curb weight as used herein is SAE's definition, the standard car as specified plus water, oil, gasoline; less optional equipment, accessories, and luggage. The standard car is defined as having the smaller of the engines it was designed to accept, a manual transmission, and a heating and ventilating system. Larger engines, automatic transmissions, and an air conditioning system are considered as optional equipment.

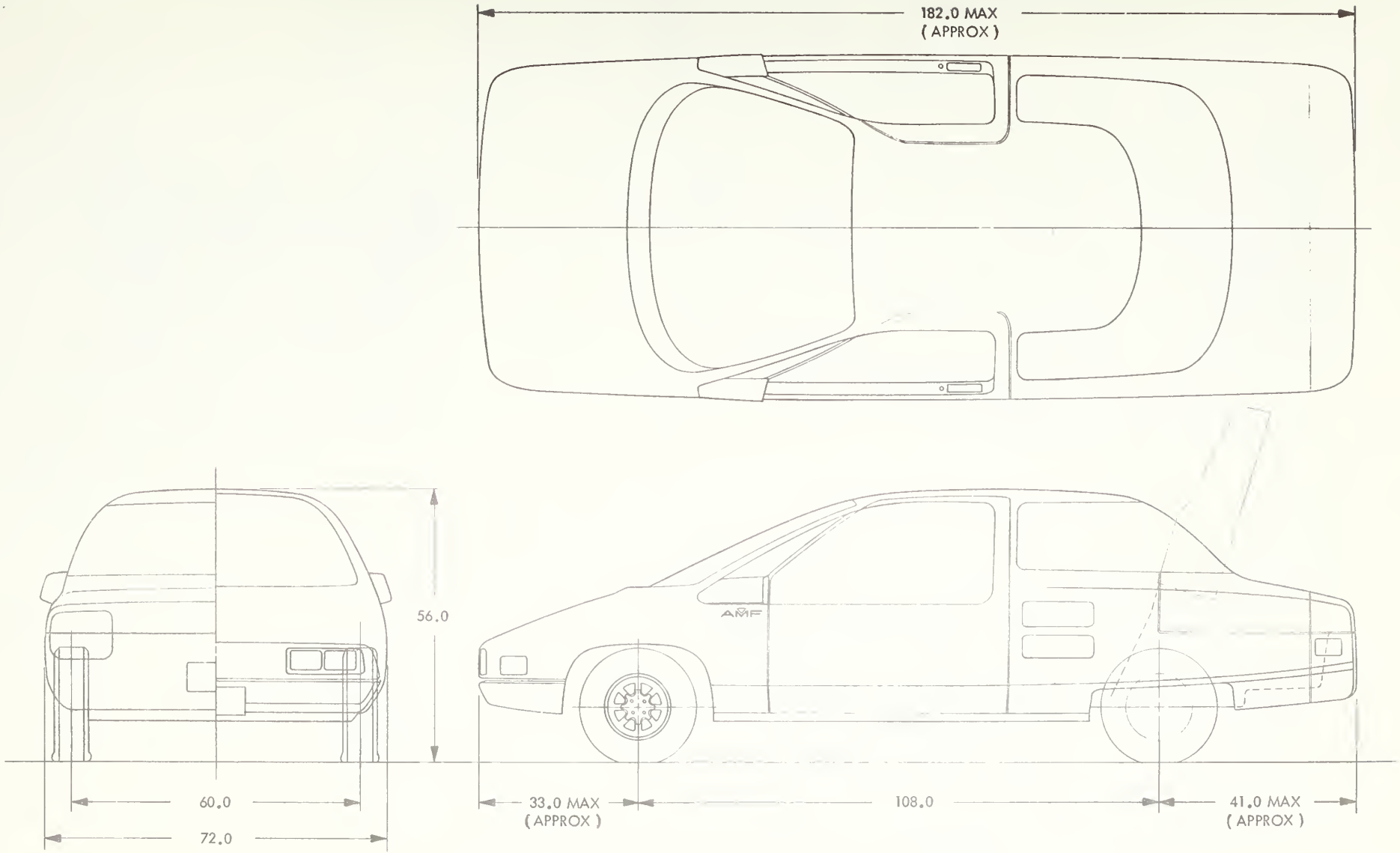


Figure 4-3. Four Passenger RSV Sedan - External Configuration (Rear Engine)

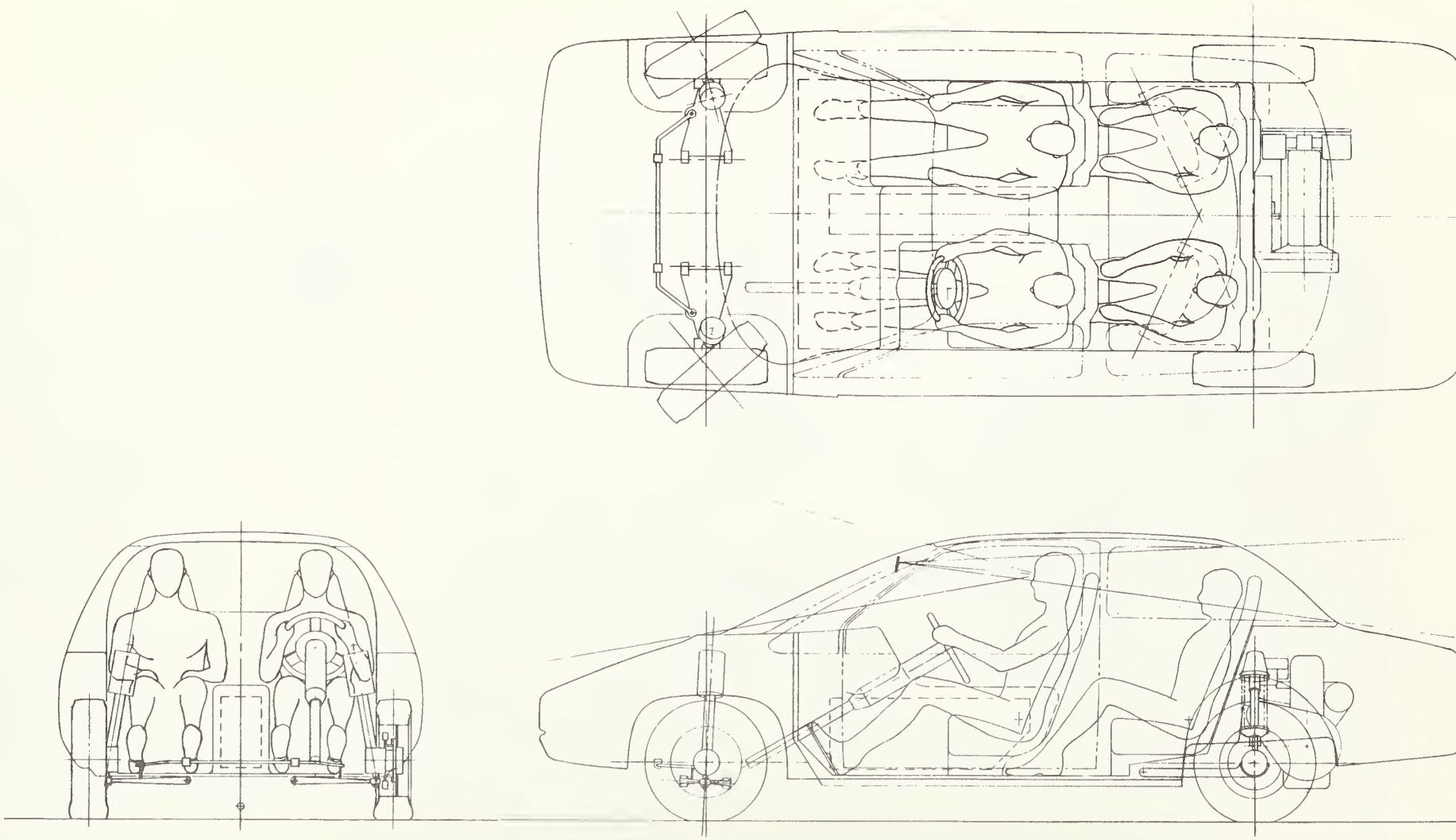


Figure 4-4. Four Passenger RSV Sedan - Internal Configuration

4.1.2 2-Passenger RSV Sedan

This vehicle can be best characterized functionally as a utility car providing essential travel needs (work-related, family business, educational, civic, and religious) at the least cost. In its anticipated role as a second car in multi-car households, its occupant comfort features would be less than that of the 4-passenger RSV sedan, but acceptable for the relatively short trip distances it would be exposed to.

Figure 4-5 depicts the external configuration of this RSV concept and Figure 4-6, the internal arrangement resulting from a front engine, front wheel drive power train. The spatial layout of the driver and right front occupant, of the controls, console, etc., are the same as that provided in the 4-passenger sedan concept to provide equivalent performance of safety related systems in the interior.

Alternative configurations of this concept are also feasible. The basic 2-passenger sedan can be modeled in a station wagon or van version, as shown in Figure 4-7, and either the wagon or van can be converted in a pick-up model. The alternatives presented are to indicate that an RSV concept need not be limited to one specific model but rather that concepts should be shown to be capable of satisfying any marketing demands.

The estimated curb weights of the 2-passenger sedan shown in Figures 4-5 and 4-6 would fall in the 2,000 to 2,500 pound range.

It should be noted that the styling configuration presented for the RSV concepts are primarily to assist in describing characterizations rather than preliminary body lines which would have been subjected to some degree of analyses, interface compatibility and other tradeoff studies.

The characteristics of the systems and hardware elements that comprise the two RSV concepts are presented in the succeeding parts of this section.

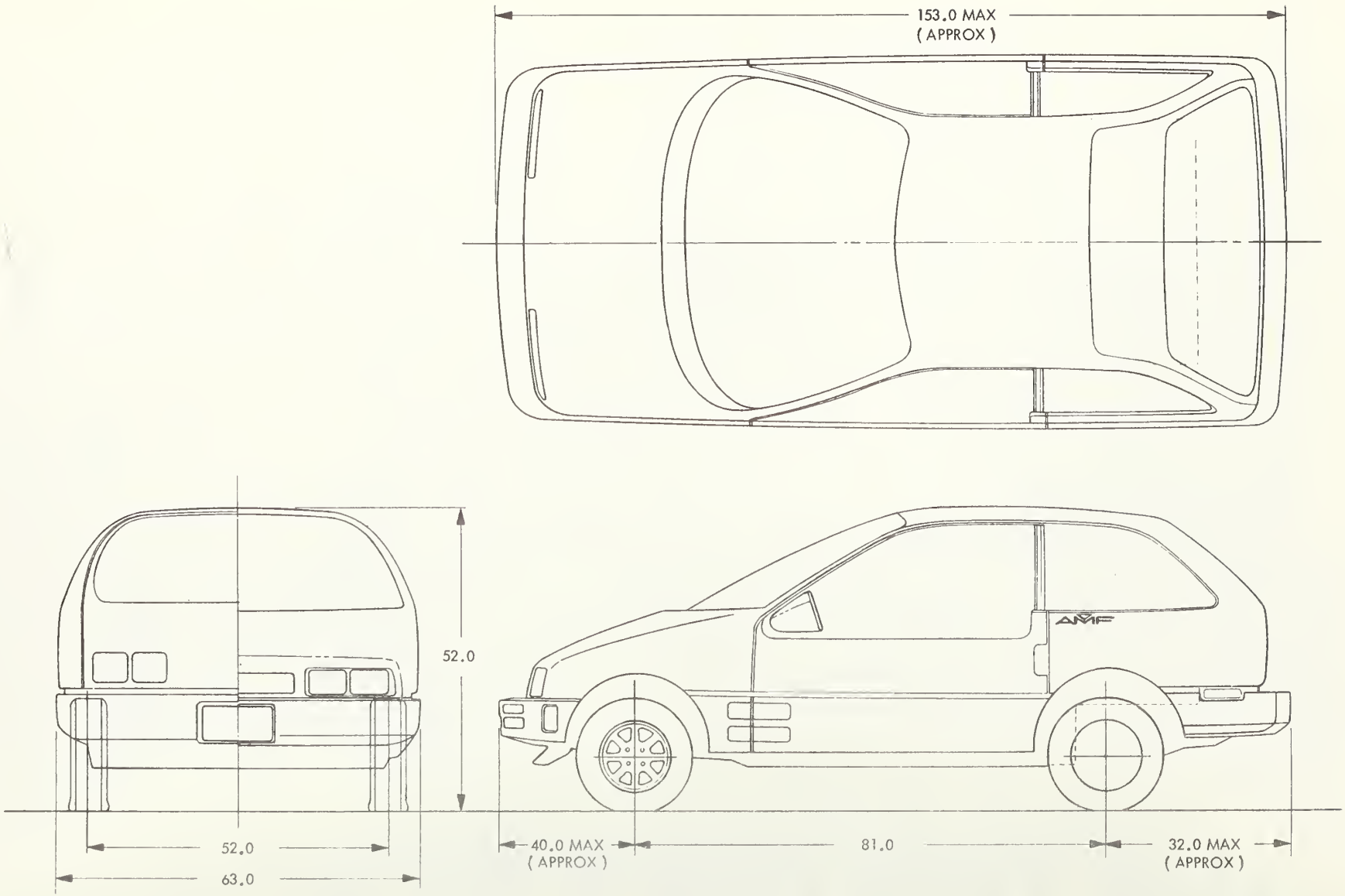


Figure 4-5. Two Passenger RSV Sedan - External Configuration

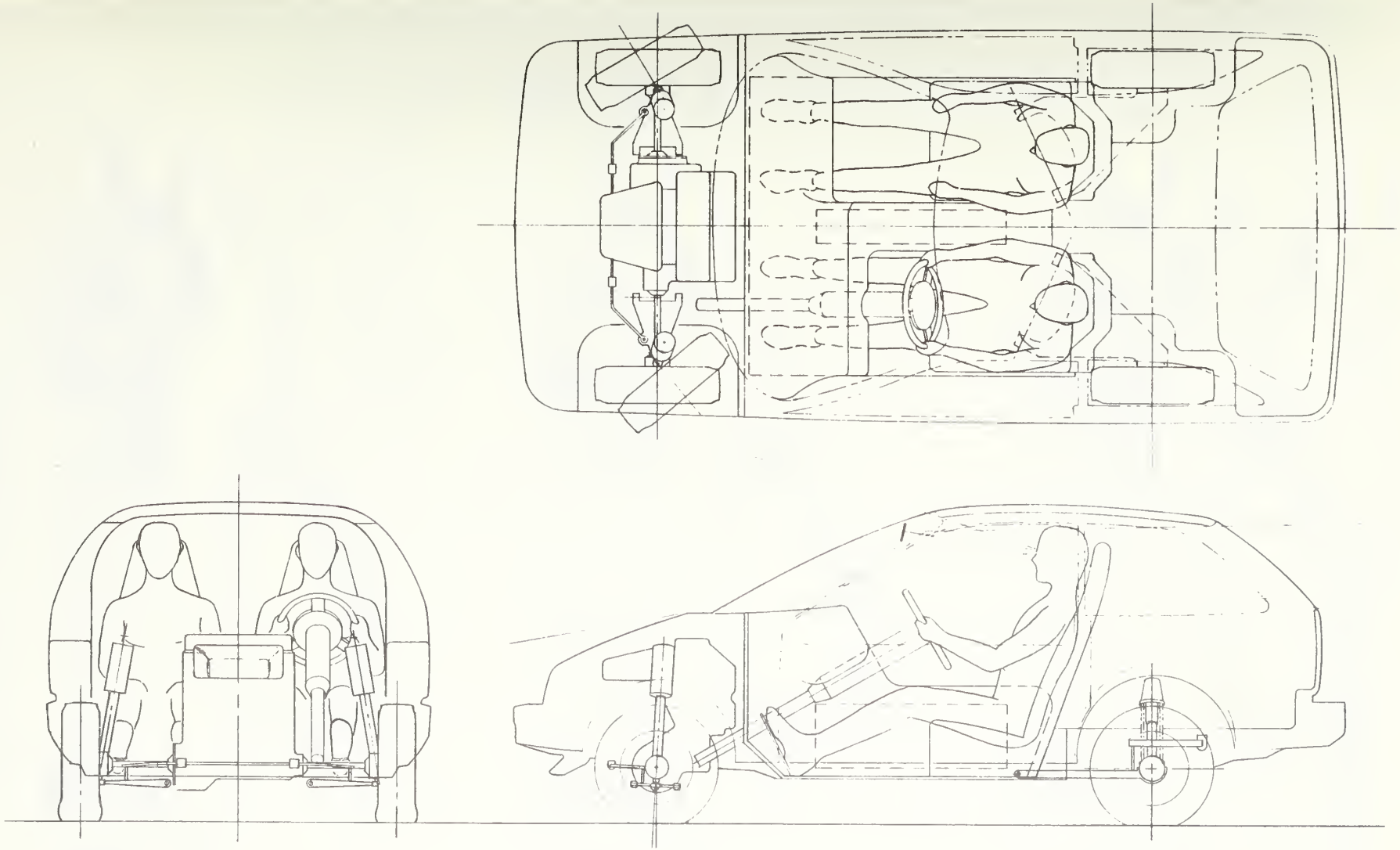
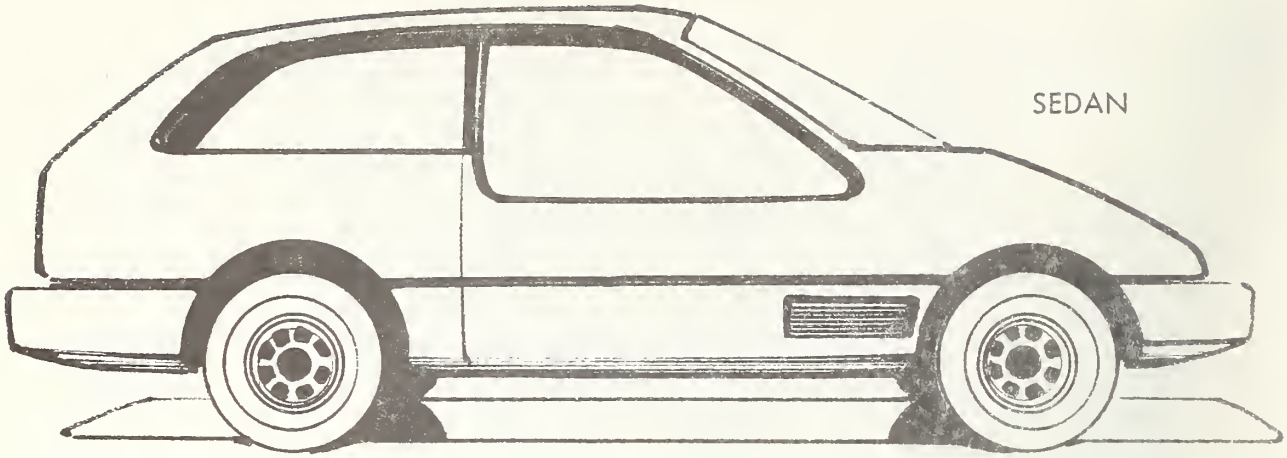
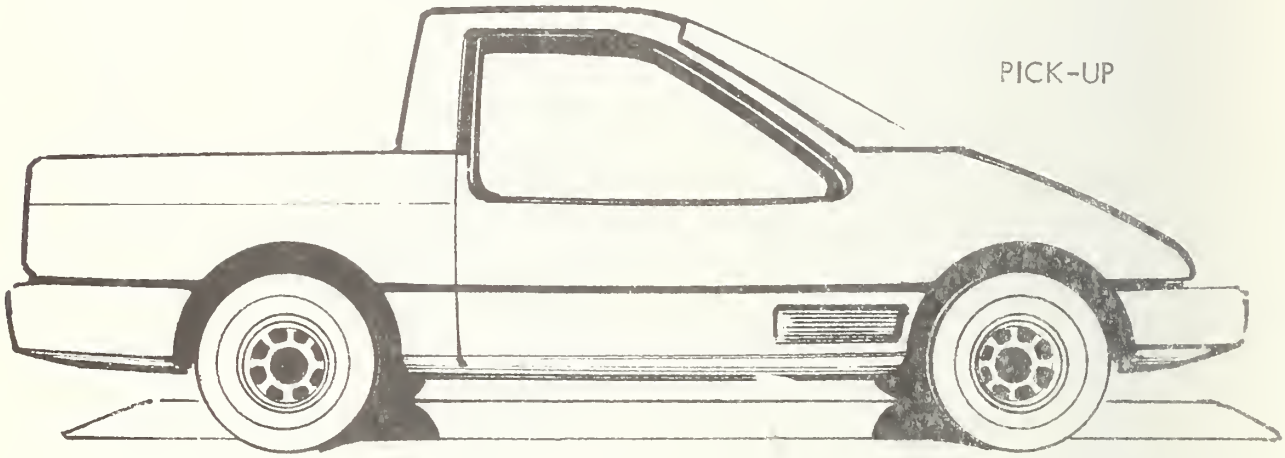


Figure 4-6. Two Passenger RSV Sedan - Internal Configuration





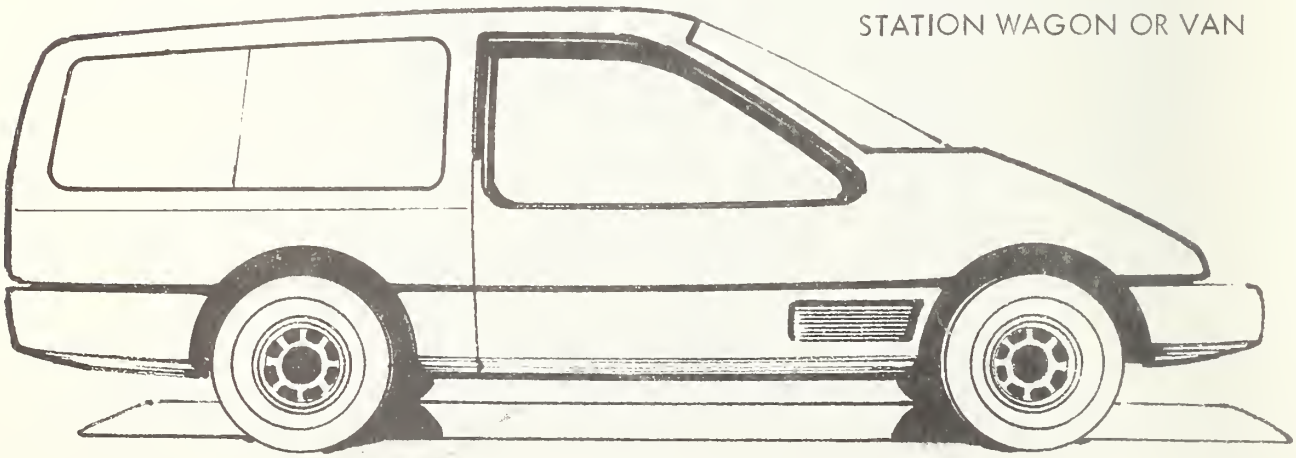


Figure 4-7. Model Variations - Two Passenger Sedan

4.2 SAFETY PERFORMANCE CHARACTERISTICS

While all elements of a vehicle system interact in providing safe performance in normal driving and accident avoidance situations and protective performance in accident situations, certain vehicle elements and subsystems are vital to safety. The characteristics of these are presented in the following descriptions; the characteristics of the functional subsystems are presented in the next subsection.

4.2.1 Visibility, Lighting, and Signaling

The driver's field of view is an important factor in the safe operation of the automobile. Ideally, the automobile driver should be provided with an unobstructed horizontal view of 360 degrees with commensurate vertical viewing angles around the vehicle. However, this maximum field of view is unattainable without degrading the automobile structure or incurring added costs for vision improvement devices. The accident statistics and literature examined in the course of this study provided no insight into inadequate fields of view as a causative factor in accidents nor what minimum viewing fields should be. Therefore, it is difficult to assess the cost of accidents caused by viewing deficiencies and consequently, to properly estimate the cost/benefit ratios of any improved viewing systems. Any device added to improve visibility becomes difficult to justify, and in particular, those that are more costly (i.e., rear periscopes and radar sensing devices) in terms of initial installed cost or operating upkeep (maintaining the reliability of the visual aid).

The characteristic of the RSV driver's viewing field is a minimum cost system with a maximum of usable visibility. The elements of the system include a maximum of glazed area within a high roof line, a low belt line and pillars that meet structural rather than styling criteria, and a rear mirror array. The array would consist of an internal mirror and external right and left side mirrors.

To maintain critical glazed areas at effective cleanliness levels, windshield and backlight washers are provided. A washer nozzle located in the wiper blade would insure proper delivery of cleaning fluid to the window surface. The wiper blades would be stored in a protected area when not in use to minimize deterioration from weather factors.

The windshield and backlight are defogged by appropriately heated air circulated near the glass area or by electrical heater elements located in the glass.

The characteristics of the lighting and signaling systems are common to both RSV concepts since they will be exposed to essentially the same usage and accident environments.

Accident data and accident studies provide no insight into current lighting and signaling systems performance as a prime or contributing causative factor. The accident projections indicate a continuation of current trends of higher fatality and injury rates during the night, and of higher night rates on rural roads than on urban roads. These conditions suggest that headlights, in particular, may play some causative role in night accidents especially at higher speeds and in rural areas. Increased road illumination with improved beam patterns would enhance forward road visibility with a minimal penalty in either cost or weight.

Current U.S. dual-beam sealed lamps have 6000 candela available as a low beam to provide night visibility of 200 to 250 feet and a high beam of 7500 candela intensity to provide visibility of 400 to 450 feet. European cars use much brighter headlights, with total intensity of 300,000 candela to provide 600 to 700 foot night visibility. The proposed FMVSS 108 Docket 69-19 Notice 3 indicates that U.S. and Europe are approaching a common maximum, the U.S. proposing a maximum of 200,000 candela and Europe reducing theirs to 225,000 candela. [1]

General Motors has proposed several new headlight systems which consist of rectangular shaped lamps with two or three beams of higher intensities as shown on the following page.

	5" x 7-1/2" Rectangular 2 Lamp System	4" x 6-1/2" Rectangular 4 Lamp System	
	2 beam	2 beam	3 beam
Low Beam	20,000	20,000	20,000
Mid-Beam	-	-	60,000
High Beam	80,000	80,000	155,000

Of the three systems, the 4-lamp, 3-beam system provides distinct advantages over current headlight systems in terms of increased forward illumination and the addition of the mid-beam provides additional illumination (over the low beam) of the right side road edge while cutting off left side to avoid glare to on-coming drivers. This system is characteristized for the 4-passenger RSV sedan, while space limitations in the smaller utility RSV and its intended usage indicate the headlight characteristics of the 2-lamp, 2-beam are appropriate to it.

Studies and tests by General Motors have demonstrated that daytime front running lights indicate vehicle presence and help in speed and distance determination of the other car in passing, intersection, and turning maneu- [1,2] vers. The required intensity of 2000 to 5000 candela for this type of daytime front running light can be obtained by using the upper beam filaments at a reduced voltage of 6 to 8 volts in the 2-lamp, 2-beam system and by an added filament in the 4-lamp systems. Since a potential though undefined benefit is to be derived from simple changes to the front headlight system, front daytime running lights are also characterized for both RSV concepts.

Various rear lighting and signaling configurations have been suggested to improve driver response of the following car; however, a common industry standard on signal functions, colors, and placements remains to be established.

Based on an evaluation of related studies in signaling, the RSV rear lighting arrangement is characterized by separate rear lamps for presence indication, stop and turn signals with both low and high rear body locations,

and a decelerating signal as shown in Figure 4-8. The two sets of stop and turn signals provide for desirable redundancy in the event of a lamp failure. Although a deceleration signal has not proven its value as a result of wide use, the relatively high incidence of injury-producing rear end accidents suggests that it would be of value in high density traffic to warn following drivers of speed reductions in downstream vehicles. The color coding for the characterized lamps is the following:

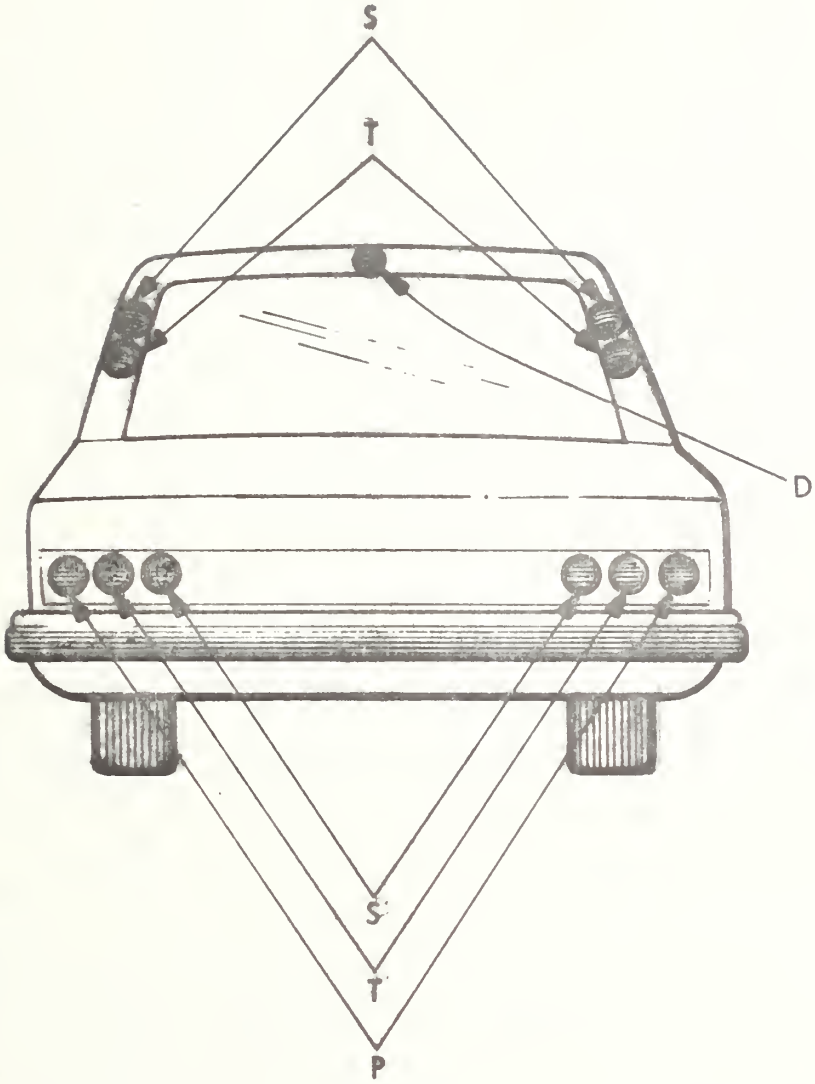
- Stop - red
- Presence - green
- Turn - amber
- Deceleration - amber

4.2.2 Riding and Handling Systems

Prior to characterizing the riding and handling systems treated in this section (braking, steering, front and rear suspensions, and front and rear wheels/tires - the power train system being treated in Section 4.3), the influence of the total vehicle configuration on these systems and their performance is discussed and the appropriate characterizations made.

RSV System

Weight and Weight Distribution. The RSV weight ranges are characterized in Section 4.1, VEHICLE CONFIGURATIONS. The vehicle's weight and weight distribution influence the performance and the design of interacting systems like suspension, braking, steering, etc. The major factor governing a vehicle's front/rear weight distribution is drive train arrangement. The 4-passenger RSV concept is configured in both front engine/front drive and rear engine/rear drive versions which are the extremes of front heavy and rear heavy arrangements; conventional front engine/rear drive arrangements fall somewhere in between these. The 2-passenger RSV concept is configured with a front engine/front drive arrangement; however, alternative arrangements are possible.



P - PRESENCE. (TAIL LIGHT)
S - STOP
T - TURN
D - DECELERATION

Figure 4-8. Rear Lighting Configuration for the RSV

Automobiles designed and manufactured in the U.S. have characteristic "understeering" yaw response which provides inherent vehicle stability up to higher vehicle speeds. Because of the RSV's lower weights and smaller wheel bases, they will exhibit an "understeer" response to a lesser degree than do larger vehicles. Since fore and aft weight distribution is one important factor which influences this yaw response behavior, the characteristic objective will be to hold fore/aft curb weight distribution within the range of 60/40 to 45/55 percent. This range of weight distribution will ensure that the desired safe yaw response can be designed into RSV's without degrading ride comfort or braking performance. The characterized weight distribution limits for the 2- and 4-passenger RSV weight ranges are shown in the table that follows:

CHARACTERIZED WEIGHT DISTRIBUTION LIMITS

	2-Passenger RSV		4-Passenger RSV	
	Curb Weight (lbs)		Curb Weight (lbs)	
Configuration Limits	2000 lbs	2500 lbs	2500 lbs	3000 lbs
Front Heavy (Front/rear, 60/40)	1200/800	1500/1000	1500/1000	1800/1200
Rear Heavy (Front/rear, 45/55)	900/1100	1125/1375	1125/1375	1350/1650

Load Conditions. The vehicle load conditions will influence both performance specifications and system designs; therefore, consideration is given to minimum and maximum vehicle loads based on vehicle occupancy factors. The characteristic load condition for the RSV's, established on the basis of their occupancy and luggage allowance, are presented in the table that follows.

RSV WEIGHTS UNDER LIMIT LOADS*

	2-Passenger RSV		4-Passenger RSV	
	Curb Weight (lbs)		Curb Weight (lbs)	
Load Condition	2000 lbs	2500 lbs	2500 lbs	3000 lbs
Driver Only Load	2245	2745	2745	3245
Full Design Load	2490	2990	3380	3880

*95th percentile male passenger - 215 lbs + 30 lbs of luggage
50th percentile male passenger - 165 lbs + 30 lbs of luggage

Overall Dimensions, Track Width and Wheelbase. These dimensions, dependent on various RSV system considerations such as the interior seating arrangement, luggage space, crashworthiness, and occupant safety requirements, etc., are shown in Figures 4-1 through 4-6. The influence of these dimensions on overturning immunity is discussed in another part of this section.

The specific riding and handling systems of interest are characterized in the subsections that follow; characterizations include both RSV crash avoidance performance and system configurations with any differences in characteristics between the two RSV concepts noted.

Braking System

Performance. The characterization of the RSV braking system considers the following:

1. Service brakes under normal low level effort.
2. Service brakes under emergency high level effort.
3. Service brakes on a split coefficient surface.
4. Service brakes under partial failure conditions.
5. Parking brake performance.
6. Performance of new system development such as anti-lock brakes, or side to side proportioning.

7. Diagnostic elements.
8. Safety critical components.

The resulting characterizations are as follows:

1. Straight Line Stopping. The RSV carrying the full design load and the driver only load, and traveling on a level road at 60 mph will stop without two wheel lock-up on any axle while remaining in a lane 12 feet wide. The stopping distance will be in the range of 150 to 172 feet from an initial speed of 60 mph. The final stopping distance will be selected to be compatible with the overall traffic flow. This stopping performance is equivalent to an average deceleration capability of between 0.7 and 0.8 g. Pedal effort allowed for straight line braking will be within the enveloped bounded by the maximum gain-minimum effort line of 0.21 g /lb and the minimum gain-maximum effort line of 0.0085 g/lb.

2. Braking on a Curve. The RSV with a full design load and a driver only load will be capable of decelerating to a stop within 73 to 86 feet, without wheel lock-up and deviation from a 12 foot lane, from a steady state speed of 40 mph on a radius of curvature path that produces 0.3 g lateral acceleration. This deceleration capability will be in a range of 0.62 to 0.73 g's. The steering effort allowed during braking on a curve will be a steering input of up to 180 degrees at a rate not to exceed 500 degrees per second. The allowable pedal effort for braking on a curve will be the same as that characterized for straight line braking.

3. Braking on a Split Coefficient Surface. The RSV with a full design load and a driver only load will be capable of stopping from a speed of 40 mph within 118 to 152 feet, when traveling on a split coefficient surface with skid numbers of 75 and 25. This performance is equivalent to deceleration capability range of 0.35 to 0.45 g's.

4. Service Brakes Under Partial Failure Condition. Two failure modes are provided for: 1, booster failure, and 2, leakage type failure of a pressure component in the service brake system. The straight line stopping capability of the RSV from an initial speed of 60 mph will be 300 ft for booster failure (0.4 g), and 388 ft for front system failure (0.31 g).

5. Parking Brake Performance. The RSV, at curb weight and when fully loaded, will hold on a 30% grade in the uphill and downhill directions. The actuation effort for hand-controlled operation will be less than 90 pounds, and for foot-controlled operation less than 125 pounds.

6. New Developments. Advanced state of the art developments, such as anti-skid or side proportioning systems, have not been characterized for the RSV concepts because a need for them was not demonstrated based on the study findings.

7. Diagnostic Elements. Lack of maintenance and poor mechanical condition of vehicles have been cited as accident causative factors; therefore, diagnostic elements in the vehicle are characterized (see Braking Configuration, the next subsection, for specific diagnostic devices) to make the driver aware of needed critical maintenance or repair. In addition to diagnostic elements in the vehicle, external diagnostic systems to examine the functional condition of various vehicle systems are being studied by the industry and a series of standards are being developed to assure interchangeability of diagnostic hookups. The RSV will conform with such developments once they are identified and accepted.

8. Safety Critical Components. Safety critical items like brake lines, brake fluids and brake pads, will conform with the applicable industry accepted practices, SAE standards, and FMVSS.

Braking Configuration. Both RSV concepts (2- and 4-passengers) will have 4-wheel disc brakes. Since these vehicles will be used for short distance trips in stop and go traffic, 4-wheel disc brakes will provide superior fade-proof performance. Small vehicles have limited space available within their wheels; for the same space, disc brakes provide better stopping capability and better heat fade performance, than do drum brakes.

The brake pads will be visible and will include embedded material which will provide an audible squeak signal when the pads are worn below an acceptable level. Diagnostic warning indicators on the RSV's will monitor brake fluid level and incipient brake failure (i.e., detect and indicate degradation failure before brake application).

Power assist for the brakes will not be necessary for the 2-passenger RSV and may not be necessary for the 4-passenger RSV; a detailed design analysis is required to determine the need for a power assist for the 4-passenger RSV.

Anti-lock brake systems are still rather bulky and expensive. While they do provide superior performance on wet and slippery surfaces, their stopping distance on normal, dry, high coefficient pavement can be less than that of conventional systems; on all surfaces, they assure steering control. In characterizing the braking system, it was decided that anti-lock features could not, at this point in the program, be justified, and in particular for the 2-passenger RSV. In order to stay within implied marketing constraints, the added weight and cost imposed on the small vehicle category by anti-lock features may require compromising more beneficial crashworthiness and occupant protection features.

The braking performance of a vehicle on split coefficient surfaces can be improved by the incorporation of negative steering geometry, similar to the negative king-pin offset on the Audi Fox. The result of this geometry is a [3] restoring torque under braking which counteracts the tendency to swerve when the two front wheels are on different surfaces. This steering feature is characterized for both RSV concepts.

To compensate for the transfer of weight from the rear to the front wheels during braking, the brake cylinder pressure in these wheels is varied by the addition of a pressure modulating valve in the rear brake line. Three basic types of such valves, deceleration-sensitive, pressure-sensitive, and load-sensitive, are available for use in a fixed front/rear braking distribution system and each can be manufactured with pressure limiting or pressure reducing characteristics. The load-sensitive valve which provides the best performance is expensive and its transducer linkage is bulky and heavy. The relevant advantages of these three types require an assessment in terms of achievable performance level, cost, simplicity of design, and suitability of installation on both RSV's; therefore, the valve type is not characterized.

A split master cylinder and dual circuit braking system is used to assure at least partial braking capability under emergency considerations. Various front to rear, side to side, and diagonal dual circuit arrangements are possible. A specific arrangement is not characterized; the candidates require analyses of effectiveness, partial failure performance, and complexity prior to any final selection for the RSV.

Steering System

Steering Response. The RSV steering response is characterized for three performance categories. Each category and its performance characteristics are described below.

1. Steady State Yaw Response. Steady state yaw response is an indication of how the vehicle will behave under the action of a constant external side force under a steady state of pavement, speed, and driver control conditions. The parameter for steady state yaw response is yaw gain, defined as yaw rate divided by front wheel angle. The control parameters are speed and lateral accelerations. In Figure 4-9, the response characteristic is shown as a function of yaw gain x wheelbase to account for different

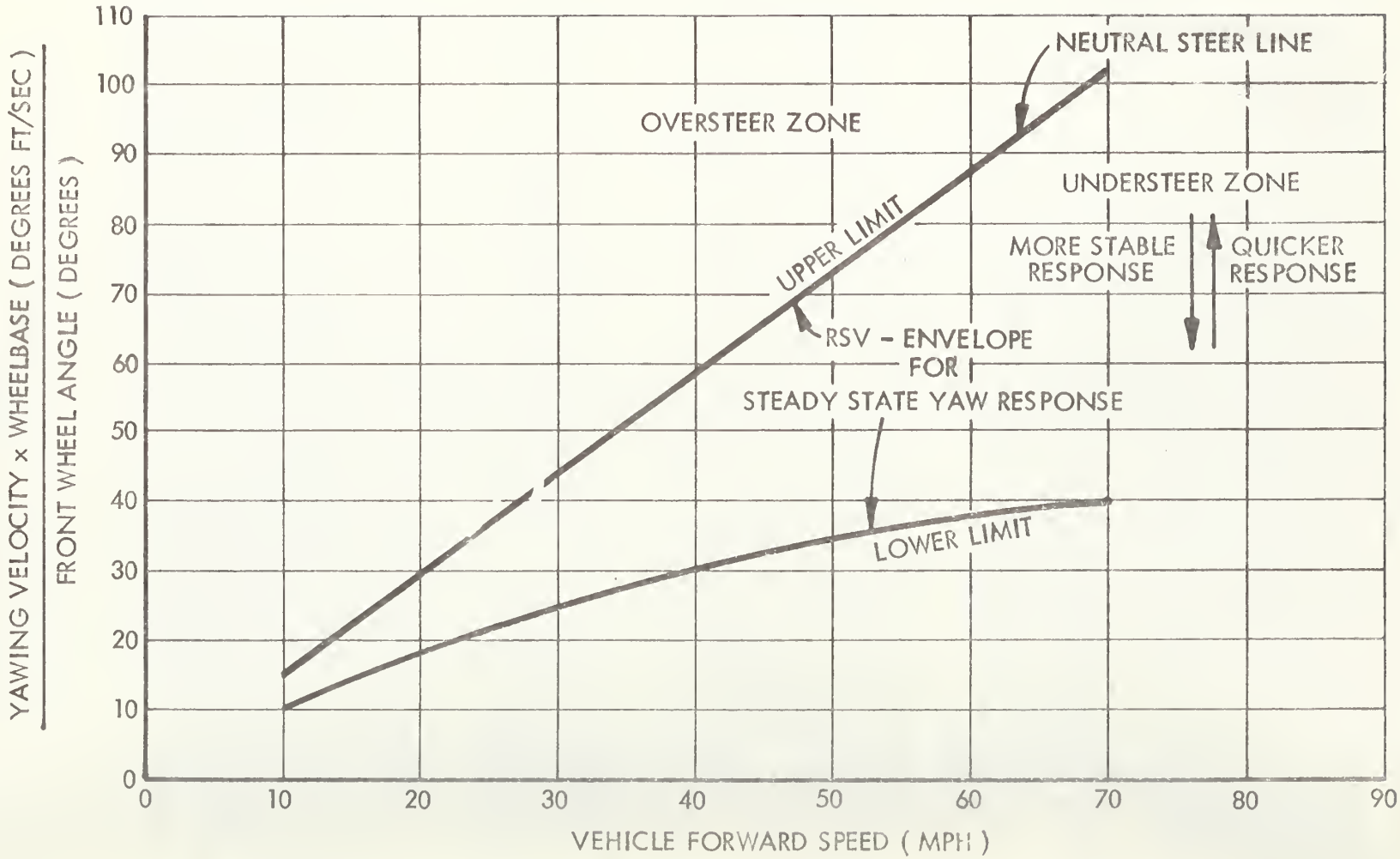


Figure 4-9 RSV Steady State Yaw Response

RSV wheelbase dimensions. The figure shows two main zones of steering response divided by a neutral steer line. In the understeer zone, the vehicle is basically stable. In understeer zone, as the yaw response approaches the neutral steer line, the vehicle stability is reduced but its yaw response to steering input is quicker. In the oversteering zone, the vehicle has a finite critical speed above which it can go into an unstable mode, but overall, the vehicle response to steering input is faster. The RSV, because of its smaller size, will have a steady state yaw response characteristic near neutral steer line. The desired characteristic envelope for the RSV, shown in Figure 4-9, will provide quick yaw response without instability.

2. Transient Yaw Response. The basic understeer/oversteer characteristics are equally applicable to the response from a transient steering action as in a rapid lane change or steering around an obstacle. In such cases, loss of control can occur in a fraction of a second. The transient yaw response goal for the RSV is to control the transient yaw gain "overshoot" and dampen it within reasonable time to a steady state value. Figure 4-10 shows upper and lower limits for 70 mph and 25 mph speeds. For these transient yaw responses, the steady state lateral acceleration value is 0.4 g.

3. Returnability. Returnability is a measure of the self-correcting capability of a vehicle's steering subsystem in a transition from a circular path to straight ahead path. The responses to be avoided are:

a. Extreme sluggishness.

b. Extremely hard kickback of steering.

c. Oscillatory transient response.

A smooth, well damped and fairly quick transition from one steady state (curved path) to other steady state (straight ahead) is the characteristic of returnability performance. This performance can be attained by a suitable selection of steering system which is compatible with suspension geometry and tire characteristics.

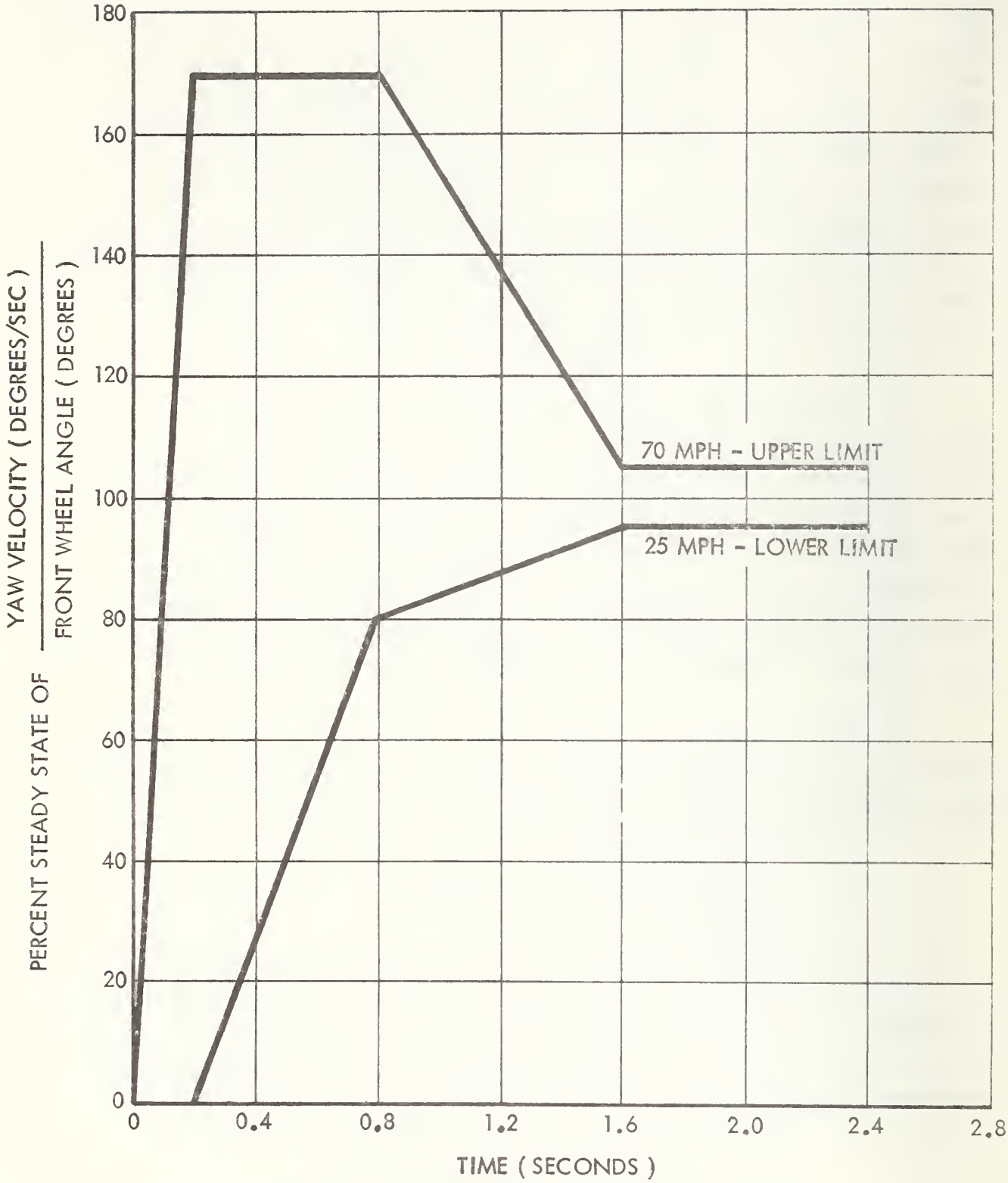


Figure 4-10. RSV Transient Yaw Response

One performance characteristic that was considered is that resulting from the inclusion of some type of adaptive or autopilot steering to enable the vehicle to overcome road irregularities and occasional side winds. The need for and benefits derived from such a feature were not obvious. [4,5]

Configuration. A rack and pinion steering system is characterized for both RSV concepts. This device is relatively small, lightweight, and provides good road feel, and is considered to be an appropriate system for cars under 3,000 pounds. Variable cam steering is an acceptable alternative system, particularly for the larger RSV in a high front wheel loading configuration. Variable steering would provide higher mechanical advantage at high steering wheel displacements (usually made in low speed maneuvers) and a low mechanical advantage with better control for the smaller steering displacements made in straight ahead driving. Manual steering, without any power assist, is selected to minimize weight; however, the front loading conditions for the 4-passenger RSV concept will require analyses to verify the adequacy of manual steering for this vehicle.

Both RSV concepts are characterized by relatively small turning circle diameters, 24 to 28 feet, to enhance maneuvering in city traffic and in parallel parking.

Handling Response

Lateral Acceleration Capability. Accident cause analyses indicate that improper tire inflation, resulting from both neglect and tire gage inaccuracies, is a contributory cause of accidents. To minimize the effects of such conditions, the RSV is characterized by a lateral acceleration capability under various front/rear combinations of inflation pressures as shown in the table that follows.

MINIMUM LATERAL ACCELERATION PERFORMANCE

Surface	Tire Pressure	Lateral Accelerations (g) (Fixed Control)
Dry Concrete or Asphalt	Design Value	0.60
	120% design value	0.60
	80% design value	0.55
	120% design, front 80% design, rear	0.63
	80% design, front 120% design, rear	0.59
Wet Concrete or Asphalt	Design Value	Dry Surface Performance Dry Skid No./Wet Skid No.

Control at Breakaway Capability. The control at breakaway performance of a vehicle is a measure of its capability to recover from a hazardous turning situation without braking. The RSV's are characterized by this capability when turning in two fairly sharp curves, 100 feet and 225 feet radius, respectively, after losing lateral grip (traction) at a maximum lateral acceleration level of approximately 0.6 g's.

Directional Stability. The RSV's will demonstrate a directional stability at speeds of 50 mph under the cross wind and pavement irregularity conditions established in the referenced procedures. Causal accident data have not [6] indicated any need for upgrading this performance level.

Because of the small size of the RSV's, manual steering is indicated and hence, the requirement for steering control sensitivity will be modified. With manual steering, the torque required to cause a yaw rate of 2°/sec will be above 5 in-lbs applied steadily at the rim of the standard wheel. The purpose of this performance level is to assure a minimum level of effort required to prevent inadvertent steering errors and yet, keep the steering control fairly effortless.

Overturning Immunity

Small vehicles are more susceptible to overturning because of their geometry. A stability factor, a geometric measure of a car's resistance to overturning, is defined by Sager and Brink as T/2H, where T is the average of front and rear track widths, and H is the height of center of gravity above ground level. The RSV design goal will be to lower the center of gravity of the RSV as much as practical and to achieve a stability factor of at least 1.5 (the average of representative current vehicles of different sizes). [7]

The desired overturning immunity characteristics for the RSV are as follows:

- Be immune to overturning on a level, paved track under a series of steering and braking maneuvers up to its maximum speed limit.
- Be capable of negotiating a slalom course, as defined in Reference 6, at forward speeds of 50 mph.
- Be capable of drastic steer and brake maneuvers, as defined in Reference 8, from initial speeds of 50 and 60 mph.

Front and Rear Suspension Systems

The attainment of good overall suspension system performance is more of a design challenge for smaller RSV type vehicles than for larger vehicles if the desired ride comfort levels, cornering capability, and overturning immunity are to be obtained.

The preceding Figure 4-2 depicts the volume allocations to ride and handling systems and the 4-wheel independent suspension system characterized for the RSV's. As one of the suspension system candidates, Figure 4-2 shows a MacPherson strut for front end and a transverse leaf spring for the rear

end. The advantage of the MacPherson strut is the elimination of the upper control link which allows the engine to be placed transversely. The rear transverse leaf spring fixed in the center, shown in Figure 4-11a, serves the dual purpose of providing vertical spring action and partial transverse rigidity to the suspension system.

As alternatives to the preceding arrangements are the two transverse torsion bars providing suspension for front end, shown in Figure 4-11b, and the two semi-trailing arms with coil springs providing suspension for the rear end, as shown in Figure 4-11c.

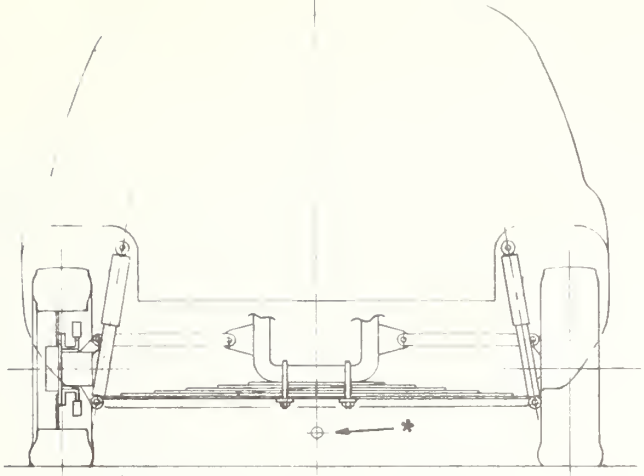
The suspension candidates for the rear engine/rear drive version of the RSV are a front end with a MacPherson strut arrangement and for the rear, semi-trailing arms, as shown in Figure 4-12a.

The candidate suspension arrangements for the 2-passenger RSV concept are a front end with MacPherson strut suspension and a rear end with semi-trailing arm and coil springs, shown in Figure 4-12b.

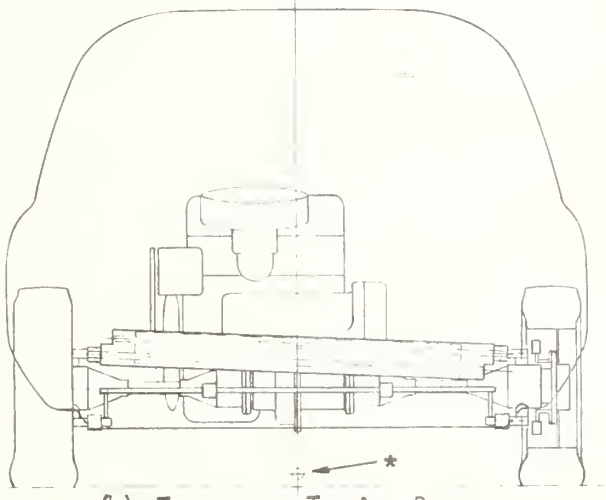
The preceding descriptions indicate the various possible arrangements of basic suspension systems and system elements. Several other candidate elements, including rubber springs, longitudinal torsion bars, viscous fluid springs, and Hydragas springs, are available for evaluation prior to a final selection for RSV use.

Since the suspension system interacts with the braking and steering systems and the mass properties of the vehicle, a balanced design of all these systems is required to achieve the characterized performance levels for safe riding and handling. The suspension system to be selected is therefore characterized by the following features:

- Geometry that provides negative steering to improve braking on split coefficient surfaces.
- Anti-dive provisions to control this motion during braking.

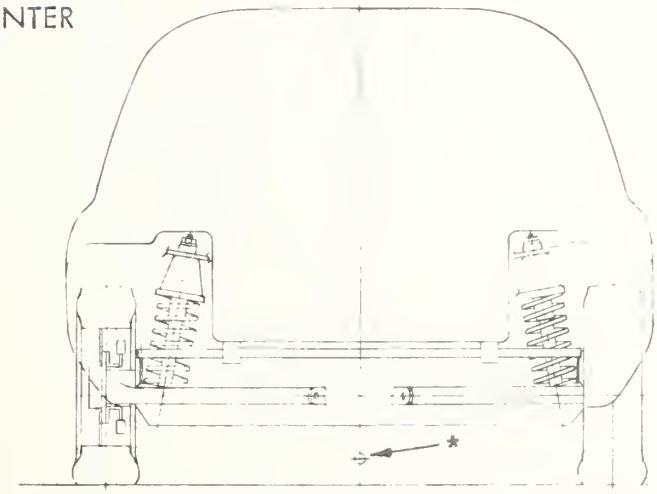


(a) Transverse Leaf Spring
4-Passenger RSV-Rear End
Front Engine/Front Drive



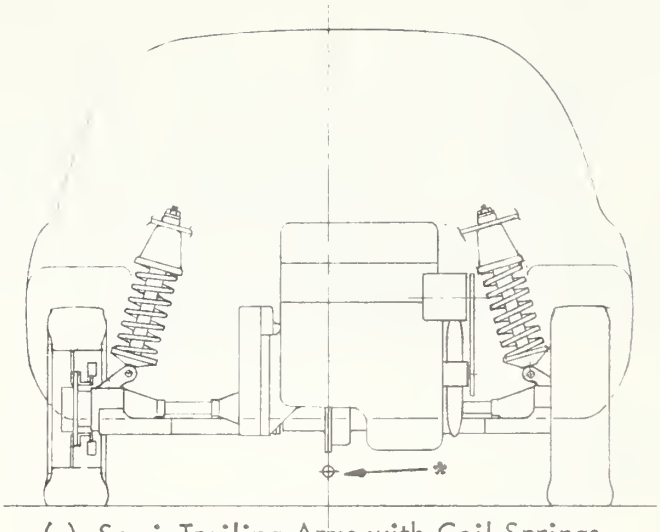
(b) Transverse Torsion Bars
4-Passenger RSV-Front End
Front Engine/Front Drive

* DENOTES ROLL CENTER
(TYP)

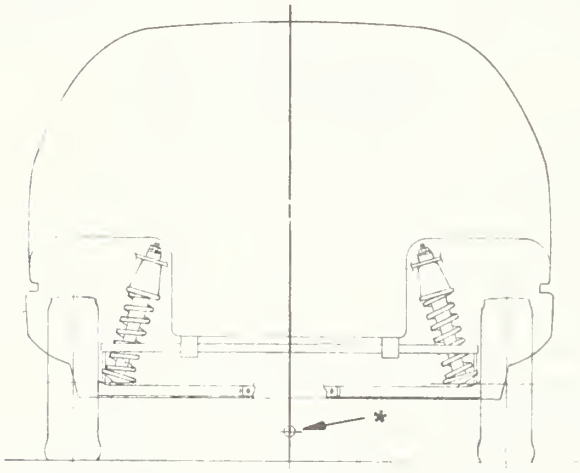


(c) Semi-Trailing Arms with Coil Springs
4-Passenger RSV-Rear End
Front Engine/Front Drive

Figure 4-11. Alternative Suspension Arrangements for RSV



(a) Semi-Trailing Arms with Coil Springs
4-Passenger RSV-Rear End
Rear Engine/Rear Drive



(b) Semi-Trailing Arms with Coil Springs
2-Passenger RSV-Rear End
Front Engine/Front Drive

* DENOTES ROLL CENTER (TYP)

Figure 4-12. Alternative Suspension Arrangements for RSV

- Controlled roll center height (typical roll center locations for the candidate systems are shown in Figures 4-11 and -12), controlled front and rear roll steer, and where necessary, stabilizer bars to bound the suspension roll stiffness. These characteristics are provided to enhance safe cornering performance.

Wheels and Tires

Radial tires with run-flat devices, providing a run-flat capability of 100 miles at 45 mph, are selected for the RSV. Anticipated advances in radial tire design (fiberglass cord, improved wet road performance) indicate this tire is highly appropriate for the small RSV.

In the front engine/front drive RSV configuration, increased demands are put on the front tires. These tires have to handle heavier dynamic loads in the vertical, lateral, and circumferential directions imposed by different road surfaces and anticipated driving maneuvers than do other engine/drive configurations. This suggests the use of different size tires for the front and rear in accordance with load distributions. Since the spare tire is eliminated and wheels can be polarized, this approach is considered feasible if required.

Tire blowout problems will be partly taken care of by run-flat devices, but keeping tire inflation pressures at a correct level remains a problem. Several small warning devices are being offered to monitor the tire pressures and give the driver a warning if pressure goes below a certain level. These devices require further evaluation of their benefits before they are specified as an RSV "need" item.

4.2.3 Crashworthiness

In this section, the required RSV system design characteristics for vehicle crashworthiness (i.e., occupant protection) are identified. The basis for this characterization are the results from the accident projections and societal cost studies (documented in Section 3.3, Societal Cost and Benefits, Volume II) showing the relative importance of the various crash modes and configurations for the 1985 time frame in terms of societal cost (a dollar value assigned as a figure of merit). This characterization effort is limited to the identification of desirable crashworthiness characteristics for the RSV based on their safety payoff potentials rather than on an evaluation of these characteristics from a cost or weight effectiveness standpoint. Cost and weight effectiveness are subject matters for subsequent analyses of crashworthiness designs.

Vehicle crashworthiness by definition is the ability of a passenger vehicle to reasonably protect its occupants from death and serious injury while exposed to the hazards encountered during driving on public roadways. For this study, the term vehicle crashworthiness is extended to the protection of those crash victims who are impacted by the vehicle exterior (i.e., pedestrians and cyclists). Reasonable protection, as used here, infers an acceptable balance between occupant protection and other important constraints on the vehicle design (e.g., cost, weight, fuel economy, emissions, etc.). A reasonable assumption here is that some level of risk associated with vehicle travel is not only acceptable but is mandatory in achieving a transportation system that makes efficient use of natural resources and is affordable by the public. A logical progression in determining the desirable crashworthy characteristics for the RSV is first to identify all desirable crashworthiness characteristics for the projected 1985 accident environment and later to test these characteristics by weighing the benefits (in terms of reduced societal costs, number of injuries, number of fatalities) against the associated penalties (i.e., cost, weight, excessive use of natural resources, etc.).

The six crash modes, recognized in this study as being representative of the 1985 crash environment, are:

- Car-car
- Car-pedestrian
- Car-fixed object
- Rollover
- Car-pedalcycle
- Car-motorcycle

The projected accident statistics for these crash modes are summarized in Table 4-1. This data clearly shows the importance of the car-car accident mode since this mode alone accounts for approximately 57% of the total societal cost associated with all of the accident modes considered. The following ranking of the accident modes (in descending order of importance) is suggested by Table 4-1:

Car-car	I
Car-fixed object	II
Car-pedestrian	III
Car-motorcycle	IV
Rollover	V
Pedalcycle	VI

It should be noted that the respective rankings remain the same for the baseline projections of costs and for the baseline projections modified by potential effectiveness of legislation, highway safety programs, and other factors enhancing driving safety in the next decade.

Naturally, when an attempt is made to efficiently allocate or budget available resources for crashworthiness, a set of priorities must be established in harmony with the potential benefits to be gained (i.e., in accordance with the relative importance of the accident modes as indicated in the rankings above).

Table 4-1

Accident Statistic Summary, Projected 1985 Crash Environment

Accident Mode	Impact Direction	Baseline Societal Costs $ Billions	Modified Societal Costs $ Billions
Car-Car		21.5	18.6
	Front	15.1	13.0
	Side	3.1	2.7
	Rear	3.3	2.9
Pedestrian		5.6	4.5
	Front	5.1	4.1
	Side	.3	.2
	Rear	.2	.2
Fixed-Object		6.1	5.1
	Front	5.0	4.2
	Side	.9	.7
	Rear	.2	.2
Rollover		2.0	1.7
Car-Pedalcycle		1.2	1.1
	Front	1.0	.8
	Side	.2	.2
	Rear	.1	.1
Car-Motorcycle		2.1	1.9
	Front	1.2	1.1
	Side	.8	.7
	Rear	.1	.1

The following discussions address the various subsystems affecting vehicle crashworthiness to derive the desirable characteristics for each subsystem which can later be tested for cost and weight effectiveness.

Vehicle Interior

The accident modes most likely to introduce injuries to the occupants within the vehicle interior are the following:

- Car-car
- Car-fixed object
- Rollover

Table 4-1 shows that these accident modes account for approximately 80% of the societal costs associated for all accident modes considered, thus indicating the importance of vehicle interior design for crashworthiness. Various studies of interior design for injury-producing sources have been conducted; the following potential impact areas have been identified as the most hazardous to the occupant during a given collision encounter: [8,9, 10]

- Steering wheel assembly
- Instrument panel
- Front windshield
- Side glazing
- Interior structure
  - Windshield header
  - "A", "B", "C" pillars
  - Doors
  - Roof
- Seats

The RSV interior is therefore characterized by a well integrated system that will restrain the motion of the occupant(s) during impact without exceeding the human tolerance limits for injury. This implies that the interior (including steering wheel assembly, instrument panel,

etc.) functions together with a primary seat restraint system in protecting the occupant during impact. For example, the steering wheel assembly is characterized by an ability to either move freely away from the occupant with little resistance (to offer maximum stroke for the primary restraint) or to assist in restraining the occupant by having appropriate crush characteristics during its collapse. Similarly, other contactable surfaces are provided with surface crush (or breakaway) characteristics that offer an acceptable interaction with the occupant(s).

Of the six accident modes studied, the car to car accident mode was estimated to incur approximately 57% of the total societal costs. This mode encompasses the three collision configurations (or directions): front, side and rear. In frontal impacts, 95% of the associated societal costs fall below a closing velocity of 100 mph. Therefore, the RSV is characterized by protecting its occupants in frontal impacts with a 100 mph closing speed (50 mph equivalent barrier speed). This value is judged to be a reasonable upper limit. A recent study by Carter indicates that it is [11] currently within the state of the art to design a restraint system to accommodate this impact speed (the achievement of this level of protection is, of course, dependent on the interior vehicle configuration and available stroking distance for the occupants). The test results of the preceding ESV program also indicate that it is currently feasible to design a vehicle so that a restraint system can be made effective at this high impact speed. In the car to car side impact configuration, the RSV is characterized by occupant protection up to approximately 40 mph relative impact speed, the level of the current state of the art for this impact configuration based on ESV findings. For rear end car to car collisions, protection up to 40 mph relative impact speed is characterized as being within the state of the art.

The dependency of societal costs on impact speed for a car impacting fixed objects indicates that this mode is more severe (here the relative

impact speed is the equivalent barrier speed) than the car-car mode, and appears to be the constraining mode for occupant protection. However, Table 4-1 shows that the estimated societal cost for the fixed object mode is less than one-third of the societal cost estimated for car to car mode. Based on this consideration, it seems reasonable to confine the occupant protection levels to reflect the car to car impact requirements, and to accommodate the crashworthiness requirements for the fixed object accident as a "spin-off" of these protection levels.

The most severe accident mode for interior protection is probably the rollover mode. Fortunately, this impact mode does not occur nearly as frequently as the car-car mode and has a total estimated societal cost of less than 1/10 of the associated cost for car-car accidents. Protection in a 30 mph rollover is characterized as a reasonable goal for the crashworthiness of the RSV interior.

A final consideration in interior crashworthiness is ingress-egress, the ease with which the individual can get into (or out of) the vehicle, after an accident. An interior design, well integrated with the vehicle structure to provide suitable means of escape following a collision and to assist those who are attempting to remove the victim(s) following impact, is a characteristic of the RSV. The primary feature is structural integrity of the interior components and the doors and door latching and locking mechanisms. In the 2-door, 4-passenger RSV concept, the front seats withstand all impact loadings without jamming their fold-down locks; the fold-down locks are placed so they are readily accessible to rear seat passengers for quick actuation in emergency situations. In a 4-door configuration, these provisions are not applicable. However, the rear doors provide a direct ingress and egress path.

Vehicle Body Structure

The vehicle body structure works jointly with the vehicle interior in protecting the occupant(s) against death or serious injury during a

collision. The body structure serves two extremely important functions in vehicle crashworthiness: (1) it limits the passenger compartment acceleration so that a restraint system can function effectively, and (2) it limits the occupant compartment intrusion to preserve survival space for the occupant(s).

The same set of impact conditions are characterized for the body structural design as those previously discussed for the interior design since both the structure and vehicle interior are to satisfy the same crashworthiness objectives, namely, to provide enhanced protection for the vehicle occupants as efficiently and economically as possible. Consequently, the discussions in the previous section pertaining to the characteristic impact configurations apply here.

The performance requirements for the body structure, however, are somewhat different than that for the interior and consequently will require a different set of characteristics. In addition to the previously noted functions, the structure has one further requirement, to minimize aggressive actions to other vehicles during impact.

From previous ESV work, it appears that reasonable restraint performance can be achieved for peak vehicle accelerations of 40 g's and 20 g's for front (and rear) and side impacts respectively. In addition, the same research effort demonstrated that general intrusion limits of three inches maximum can be satisfied at relatively high impact speeds with nominal weight penalties. Similar structural characteristics are set for the RSV with the possibility of relaxing the intrusion requirements somewhat to allow greater intrusion in non-critical areas. The desired structural characteristics for the RSV thus include the following:

- Passenger Compartment Acceleration Limits

Front/rear	40 g's
Side	20 g's

- Passenger Compartment Intrusion

Critical areas	3 inches
Non-critical areas	As justified by technical considerations (must not create sharp protruding surfaces into the compartment).

Additional characteristics required of a crashworthy body structure stem from the fact that most real world accident configurations are not "ideal" (i.e., some degree of obliquity is involved) and consequently, a practical crashworthy vehicle structure must possess suitable crush characteristics with energy absorption capability to accommodate these non-ideal impact situations.

Although not necessarily safety related, a desirable feature of the RSV structure is low impact speed protection for the body structure to minimize costly repairs resulting from relatively minor accidents which frequently occur at low speeds in congested areas (i.e., city streets, parking lots, etc.). Based on the current state of the art in bumper system design, a 5 mph (equivalent barrier speed) system is characterized for the RSV. This level of protection is a reasonable one and incurs only a nominal weight penalty.

Vehicle Body Exterior

Of the six accident modes considered in this study, those involving exterior vehicle impact with a pedestrian, a motorcyclist or a pedal-cyclist pose the greatest threat to the crash victim(s). The characterized RSV exterior configuration is one which minimizes the hazard associated with exterior impacts. The suggested cost effective approach to accomplish this is simply to streamline the vehicle so that all sharp protruding surfaces located in the vicinity of the point of impact are eliminated or are de-hostilized, contacted surfaces absorb impact energy, and further to shape the front structure so that the tendency is for the

victim to be thrown away from the vehicle rather than be captured and forced beneath the vehicle. These design techniques are complementary to aerodynamic drag reduction considerations important for fuel economy. Properly shaping the vehicle structure for controlling the victim's trajectory should prove to be effective, especially for speed impacts above 20 to 30 mph, since only a fraction of the total available energy will be imparted to the victim.

Occupant Restraints

The RSV is characterized by an occupant restraint system which includes those devices in the vehicle interior that are designed to mitigate the impact forces acting on the occupant(s) during a crash event. The following types of restraints are recognized as candidates for use in the RSV:

- Passive deployable restraint
- Passive deployable restraint and active lap belt
- Active torso and/or lap belt
- Passive torso belt, and passive knee restraint
- Active torso belt and passive knee restraint

The specific type or combinations of restraint systems to be used in the RSV is dependent on the cost effectiveness of each design when subjected to the projected accident environment. Therefore, only generalized characteristics of the restraint system are presented.

The restraint system, characteristically, is capable of providing protection for the occupants while the RSV is undergoing front, side, rear, and rollover impacts. Further, the system minimizes bodily contact with the vehicle interior. This implies ample room to stroke the restraint,

without the occupant encountering harsh obstructions, for the full range of impact speeds and of occupant sizes (5th percentile female to 95th percentile male).

The occupant restraint is characterized as providing a minimum level of protection for the full occupant size range as specified in FMVSS 208.

4.3 FUNCTIONAL PERFORMANCE CHARACTERISTICS

4.3.1 Propulsion (Power Train) System

Since two RSV configurations have been characterized, the description of the propulsion system appropriate to either RSV is presented in parametric terms with vehicle weight as the variable.

The characteristics of the propulsion system are determined by a number of factors including acceleration capability, fuel economy, and the weight and size of the system. These factors directly or indirectly influence safety performance, total vehicle weight, and the first and operating costs of the vehicle.

In order to keep the size and weight of the system to a minimum value, a minimum acceptable performance level (in terms of acceleration) is desired ("Hot" performance is considered incompatible with the projected availability of resources in the mid-80's). In terms of performance, good acceleration in the low speed portion of the vehicle speed range is considered desirable. As an example, typical vehicle and propulsion system characteristics (considering both 3- and 4-speed transmissions) for the utility RSV concept are the following:

- Vehicle weight — 2350 lbs test weight (2000 lbs C.W.)
- Frontal area — 20 ft^2
- Drag coefficient — .40

	Gear Ratio	
• Gear	4-speed	3-speed
1	2.46	1.81
2	1.81	1.27
3	1.27	1.00
4	1.00	
• Power	75 hp @ 5000 rpm	
• N/V	66.67 rpm/mph	

These system configurations result in the following performance:

	Time to Top Speed, seconds		
Speed Range, mph	4-speed	3-speed	Difference
0-10	2.4	4.0	1.6
0-20	4.3	6.8	2.5
0-30	6.6	9.7	3.1
0-40	9.6	12.9	3.3
0-50	13.6	17.0	3.4
0-60	19.4	22.8	3.4

The extra gear added to the transmission at the low end gives added performance in the speed range to 30 mph. From 30 mph and higher, there is very little performance gain, the gain reaching a plateau above 40 mph.

In order to select the lightest weight and smallest size power plant, it becomes necessary to limit the power output. In current piston engines, the higher the engine operating speed range, the smaller the engine becomes for the same power output. Higher operating speeds tend to cause more wear and produce more noise. An evaluation of the desired parameters compared against the negative aspects will have to be made before the final selection of a power plant is made for the RSV.

A series of propulsion system characteristics for vehicles having test weights of 2350, 2900 and 3450 pounds (equivalent to the estimated curb weight range of the two RSV concepts) were calculated. Figure 4-13 shows the road power needed to obtain a specified performance level for the three weights. The power available curves are based on a 4-speed transmission and a power characteristic that is obtained from current automotive engines. The piston engine is not now selected as the RSV power source, however, the power shown as available from such an engine and transmission is characterized for the RSV. The power required curve shows the amount of power needed at each speed the vehicle attains for the specified performance. The curve indicated as level road power is the power needed to keep the vehicle at constant speed. The difference between the level road power and the power available curve is the acceleration power, that is, the power needed to accelerate the vehicle throughout the total speed range. The power available curves in these cases are positioned by selection of power gear ratios to give high acceleration at low speeds and also to limit the top speed of the vehicle. The second road power curve denotes the power required to negotiate a five percent slope. The performance and power requirements for the vehicle weight considered are summarized as follows:

Vehicle curb weight, lbs	2000	2500	3000
Vehicle test weight, lbs	2350	2900	3450
Max. engine power, hp	70	84	95
Max. power available at wheels, hp	46	56	63
Max. speed, mph	83	85	85
Time to accelerate to 30 mph, sec	6.5	6.5	6.5
Time to accelerate to 40 mph, sec	9.6	9.4	9.5
Time to accelerate to 50 mph, sec	13.6	13.4	13.8
Time to accelerate from 30 mph to 60 mph, sec	12.8	12.6	13.3
Max. speed on 5% slope, mph	64	65	64

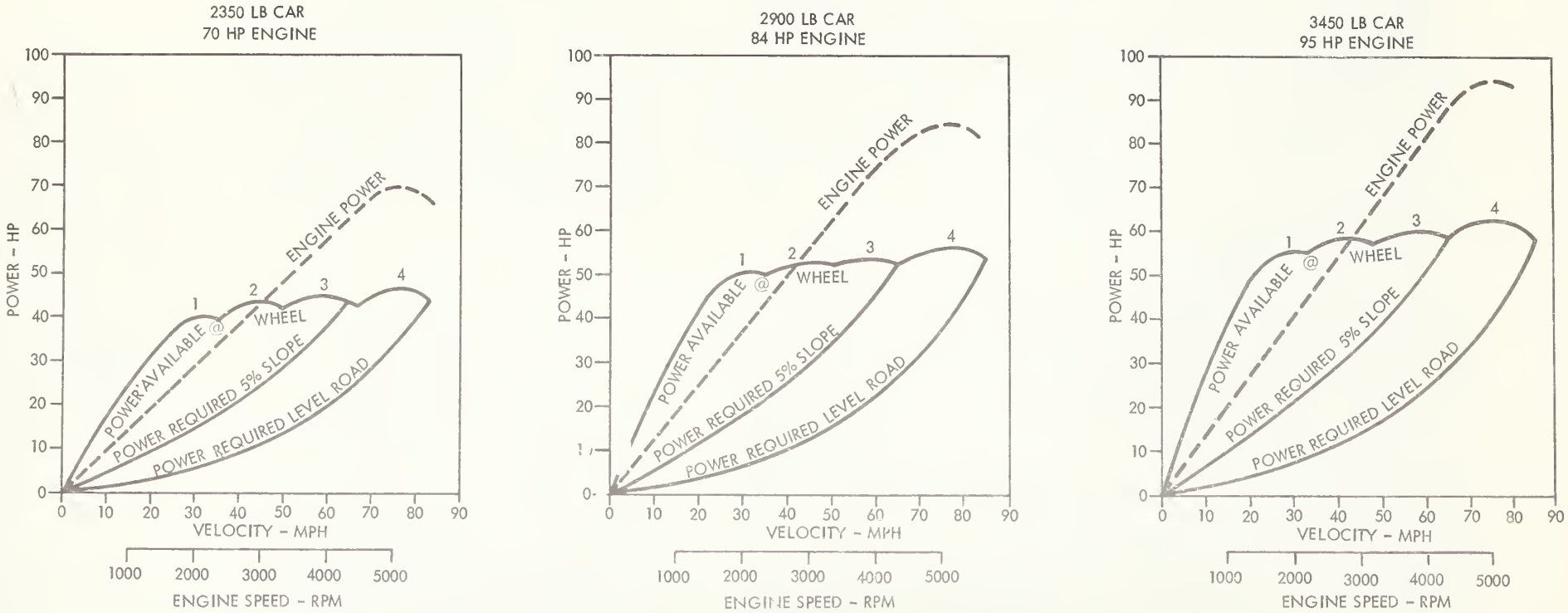


Figure 4-13. Road Power Available and Required for Three Test Weight Cars of Equal Acceleration Performance

These performance values with their respective power plant outputs are characterized as minimum acceptable performance. Higher powered engines could be installed with better performance as options. For example, increasing the power for the 2900 pound test weight vehicle from 84 to 104 hp increases the acceleration as follows:

Acceleration from mph	Time, seconds
0-30	5.3
0-40	7.6
0-50	10.7
30-60	9.5

Also, increasing the power for the 3450 lb test weight vehicle from 95 to 137 hp increases the acceleration for various speed ranges as follows:

Speed Range, mph	Time, seconds
0-30	4.2
0-40	6.2
0-50	8.9
30-60	8.1

These power increases would result in increases in the size and weight of the power plant and fuel consumption. The increased fuel requirements depends on whether the extra power is used for performance. If a comparison is made of the lower and higher powered cars driven on the same driving cycle, then the fuel economy does not suffer as much. It is estimated that a 10% increase in engine size only increases fuel consumption by only 2% when the car is driven on the federal cycle. However, a higher performance vehicle will be driven at higher accelerations, thereby increasing fuel consumption to much higher values and such a characteristic is deemed to be inappropriate to the objectives of the RSV program.

4.3.2 Accessories

To achieve a minimum weight and to conserve fuel, the RSV is characterized with a minimum of accessories. Provision for optional accessories are made but these are not installed in the "standard" version of the RSV.

Heating, ventilating and defrosting or defogging units are provided; air conditioning is an optional accessory, not installed. Ventilation is of the flow-through type without the necessity of opening windows. Heating is obtained by using engine waste heat as in current practice. Defrosting and defogging utilizes the heat from the heating system; electrical heating by resistance elements located in the glass is an alternative system.

A ratio is provided to make broadcasted weather, traffic conditions, and other road information available to the driver.

Courtesy lighting is used to illuminate the car interior and doorways when entering or exiting the car and provide a light source for map reading.

The RSV is equipped with a manual shift transmission with the option of an automatic transmission. To date, manual transmission drive trains provide a substantial savings in fuel consumption. Since energy supplies are projected to be marginal in terms of meeting demand in 1985, use of the most efficient form of drive train, and all other energy consuming devices, is indicated.

4.4 SUPPORTING RATIONALE

The characteristics described for the RSV in the preceding sections were based on indicated needs resulting from the projected usage and accident environments, current and anticipated developments in vehicle designs, and related studies concerned with vehicle safety performance. This section discusses the rationale used in developing some of the more vital RSV characteristics and the various data and study findings used in support of the rationale.

4.4.1 Visibility, Lighting, and Signaling

Current rear lighting systems provide the following visual information:

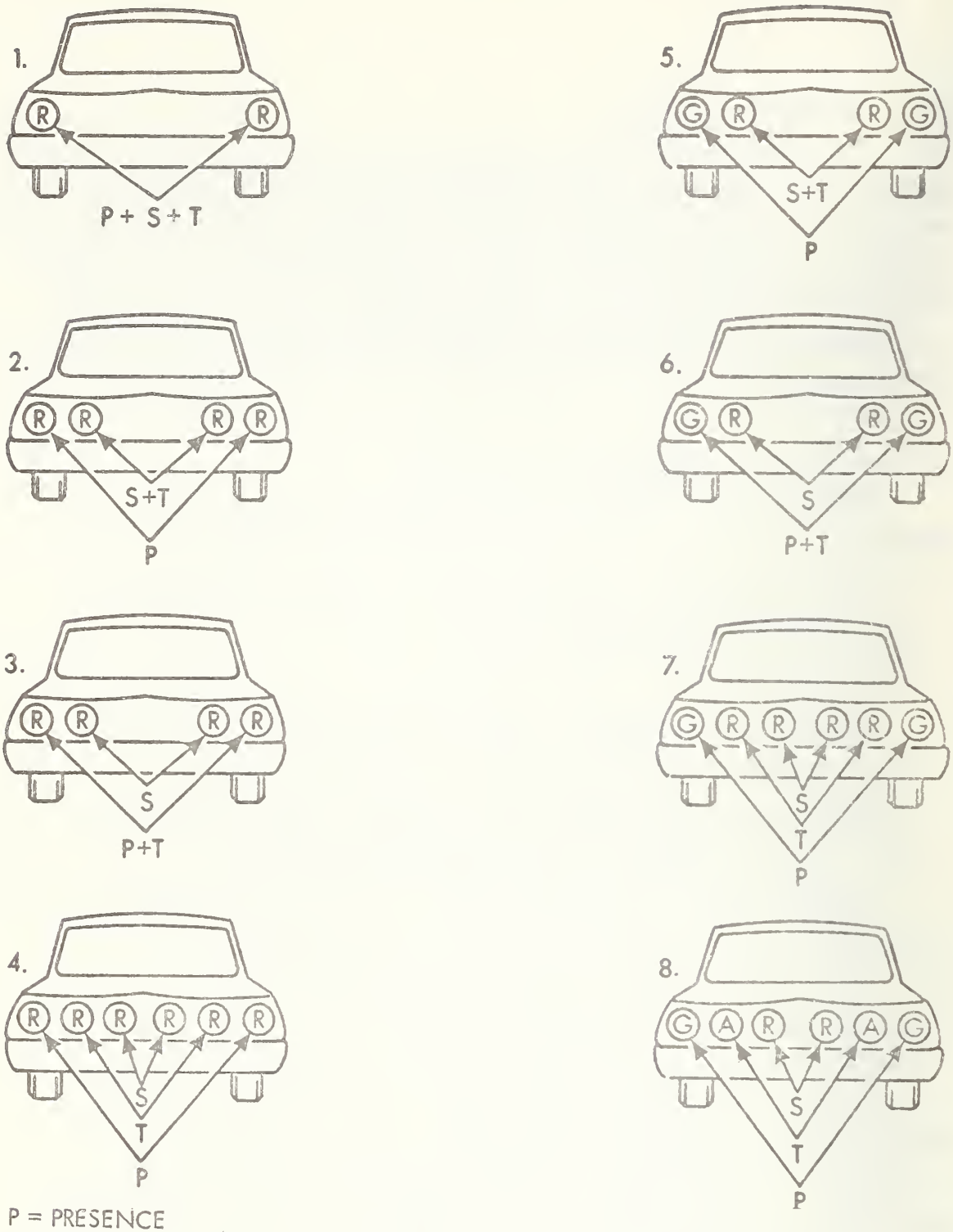
a. Brake signals - automatically activated when the driver applies the service brakes.

b. Turn signals - driver activated by the turn signal switch.

c. Taillight (presence) - driver activated with the headlight switch to show the presence of the car at night.

d. Backup light - automatically activated when the gear shift lever is engaged in the reverse gear position.

Generally, the brake signals, turn signals and taillights in production cars are all located in one area or lamp cluster usually red in color. In a Highway Safety Research Institute (HSRI) study, the coding [13] systems of seven rear lighting configurations were evaluated by a series of carefully controlled night driving tests of specially instrumented vehicles running on city and county roads. The lighting configurations studied, shown in Figure 4-14, consisted of various combinations of the number of signal lights, the functional separation of lights, and signal colors. Various signal modes, listed below, were used and reaction times of following drivers to respond to those modes were measured.



P = PRESENCE
S = STOP
T = TURN
R = RED
G = GREEN
A = AMBER

Figure 4-14. Rear Lighting and Signaling Configurations

1. Turn signal, both left and right
2. Stop signal
3. Turn-stop signal (stop signaled after a previously initiated turn signal was on)
4. Stop-turn signal (turn signaled after a previously initiated stop signal was on)

In the comparisons of reaction time to these signal modes and configurations, the following performance was indicated:

1. No significant difference was noted in the system performance in the stop signal mode.
2. In the turn, the stop-turn, and the turn-stop modes, the current conventional system (System 1 in Figure 4-14) was found to be inferior to the experimental system with additional codes such as number of lights, color, and functional separation.
3. In the turn mode, those systems (1, 3, 6) which combined the presence and turn signals in one lamp produced the poorest performance. The green turn signal-presence combination (System 6) was not as effective as the red equivalent (System 3).
4. In the turn-stop mode, there were significant improvements when the red presence-turn lamp was separated, or when the green presence-turn lamp was separated from the red stop lamp, or when the red lamps were all separated. The most effective signaling was obtained when complete separation and color coding (System 8) was used.
5. In the stop-turn mode, systems employing complete functional separation of lamps (Systems 4, 7, 8) were superior to all others.

GM conducted tests and demonstrations jointly with NHTSA on various rear lighting arrangements. In their evaluation tests for determining [2] whether the signaling functions of stop and turn are to be separated or combined, they found that some separation was desirable. The highest rated system was one with combined presence, turn, and stop signals and additional lamps containing stop and turn signals located high on the rear of the vehicle. Separate stop, turn and presence lamps were rated no better than a cluster combining all three signal lamps. These tests were purely subjective, no response time measurements were made.

4.4.2 Riding and Handling Systems

In order to develop a basis for RSV characterization and subsequent performance specification development, a literature search was conducted to acquire any available information on accident causation factors associated with the riding and handling systems as well as with the related vehicle systems (i.e., visibility, lighting, signaling, etc.) which influence accident avoidance performance. The accident data analyses, presented in Section 3.2 of this report, were non-productive in terms of defining the cause and effect factors associated with the riding and handling systems. The next part of this section summarizes the findings of other investigators which are of interest to characterizing these systems.

Causal Factors. Accident statistics, available from several sources, vary in both depth and volume. Whatever the depth of the investigation, the amassed statistical data can be analyzed on the basis of the well accepted 3 x 3 basic matrix shown in Figure 4-15. The matrix consists of three accident phases and of three accident factors; the phases are: (1) pre-crash, (2) crash, and (3) post-crash; and the factors are: (1) human, (2) vehicle, and (3) environment.

FACTORS OF ACCIDENTS	PHASES OF ACCIDENTS: PRE-CRASH	CRASH	POST-CRASH
HUMAN	1 HUMAN - PRE-CRASH DRIVER, OCCUPANT, PEDESTRIAN DETAIL DATA. ATTEMPTS TO AVOID ACCIDENT. DRUG CONDITION, RESTRAINT USE, ETC.	2 HUMAN - CRASH EJECTION/RESTRAINT OBJECTS STRUCK OBJECTS STRUCK BY INJURY SEVERITY, TYPE, AND LOCATION, ETC.	3 HUMAN - POST-CRASH LOCATION AT END OF ACCIDENT MEDICAL CARE EXTRICATION ETC.
VEHICLE	4 VEHICLE - PRE-CRASH VEHICLE DESCRIPTIONS MALFUNCTIONS TYPE OF PRE-CRASH MANEUVER CAUSAL FACTORS, ETC.	5 VEHICLE - CRASH LOCATION AT IMPACT OBJECTS STRUCK IMPACT DIRECTION, ETC. VEHICLE POSITION DAMAGE SPEED AT IMPACT, ETC.	6 VEHICLE - POST-CRASH VEHICLE TRAJECTORY AFTER INITIAL EVENT VEHICLE FINAL POSITION ADDED DAMAGE FACTORS ETC.
ENVIRONMENT	7 ENVIRONMENT - PRE-CRASH ROAD AMBIENCE ILLUMINATION TIME VISIBILITY CAUSAL FACTORS, ETC.	8 ENVIRONMENT - CRASH ROAD CHARACTER AND PECULIARITIES AT IMPACT DAMAGE TO ROAD AND STRUCTURES ETC.	9 ENVIRONMENT - POST-CRASH EXTENT OF LOSS DEBRIS DEPOSITED TRAFFIC FLOW ETC.

Figure 4-15. Basic Accident Data Matrix

The search for causal factors was concentrated on the pre-crash phase. It is obvious that the vehicle's accident avoidance systems play a major role in the pre-crash phase although these systems do influence, to a lesser extent, the crash and post-crash accident phases. But the details of the pre-crash phase hold the clues to the accident causal factors.

Ideally, causal factors data should be had for both accidents avoided and accidents that took place nationwide to draw meaningful conclusions as to relative effectiveness of various system designs and performance levels. Unfortunately, avoided accidents are not reported.

The current multiplicity of accident reporting and investigation agencies, the diversity of reporting objectives, and the cost of uniform in-depth reporting preclude the establishment of causal factors and conclusions based on the available national accident data.

This lack of data base is referred to by many investigators. Ingram and Oppenheimer conclude that more accident studies are necessary [14] to evaluate cost effectiveness of various braking systems. Limpert and [15] Gamero have realized the need for relating vehicle crash avoidance performance to accident causes and proposed a method for determining critical system speeds under various maneuvers to enrich the causal data statistics. Recently, the GAO requested NHTSA "to expedite an authori- [16] tative accident cause data system so it can set priorities and justify safety standards."

In the absence of representative national data, available causal data in smaller sample sizes and considering any biases, was examined to reveal causal factors of interest.

The report, "Summary of 1968-1970 Multi-Disciplinary Accident [17] Investigations (MDAI)", presents an aggregation of factors which, in the judgment of the investigating teams, were injury and accident cause related. The factors were categorized as positive and negative; the positive factors

were those which mitigated the severity of the accident, and the negative factors were those which increased the likelihood of accident or injury. For pre-crash phase, the reported contribution by human, vehicle and environmental factors in a total of 448 cases analyzed is as follows:

	Frequency			
Factor Class	+ Factor	- Factor	Total	% of Total
Human	12	865	877	65
Vehicle	0	182	182	13
Environment	1	300	301	22

With respect to the components in vehicle factors, conclusions are stated very cautiously. General improper or inadequate maintenance resulting in a degraded vehicle condition was reported as the dominant factor; 17 such cases were directly cited. Brake systems were reported as contributory causes in some manner in 27 cases, and tire failures or improper tire condition was cited in 51 cases. Environmental pre-crash factors which contribute to the initiation of an accident were categorized in four major areas: (1) traffic control inadequacies, (2) poor roadway geometry, (3) inadequate roadway maintenance, and (4) ambient conditions. Ambient conditions was the largest category and involved wet, slippery pavement; 70 cases were reported under this category.

J.R. Treat and K.B. Joscelyn analyzed 999 on-site Level II cases [18] including 219 MDAI level cases. Their objective was to rank the relative rates of human, vehicle and environmental factors as contributory causal factors. Their distribution of causal factors, shown below, includes many accidents involving two or more causal factors and hence the indicated total adds up to more than 100%.

Factor	Percent
Human	85 to 97
Vehicle	6 to 18
Environment	18 to 34

The principal components in the vehicle factors were brakes (improper maintenance), communications systems (lights, signals, obscured vision, etc.), and tires (either worn out or underinflated). The steering and suspension systems were infrequently mentioned. The quality of maintenance in accident-involved vehicles was found to be inferior to that in the general vehicle population.

K. Perchonok analyzed a total of 1,850 cases, including 242 MDAI [19] cases. In order to obtain a better insight into accident causation, human and vehicle, and human and environment factors were combined as additional causal factor categories. The reported distribution of causal factors in these five categories follows.

Factor	Percent
Human	57
Vehicle	4
Environment	8
Human/environment	30
Human/vehicle	1

The human related causal factor again predominates the distribution. Vehicle related factors were unexpected malfunctions and sudden breakdowns. Usually, the breakdown was realized only when the driver's control input did not result in the expected vehicle response.

It is apparent from the preceding summary of studies that they are consistent in one respect, namely, that human factors are the leading causal factor followed by environment and vehicle. R.T. Bundorf noted in an [20] analysis of some of these studies that: "The foregoing data may be interpreted to indicate either that vehicle design factors relating to handling are not principal factors in accident causation or that they are important factors and the investigators have not learned to identify them. There is a definite lack of useful information for establishing objective safe handling criteria for vehicles in either new or in-use conditions".

Booz-Allen Applied Research Incorporated conducted a detailed vehicle safety analysis to identify and rank vehicle failure modes according to their criticality. The major conclusions reached in the study were: [21]

1. Braking system performance is critical to vehicle safety. Introduction of dual master cylinder design reduced the likelihood of complete brake loss but introduced new partial failure modes.

2. Front suspension system components are critical and inspection techniques require improvement.

3. Vehicle acceleration capability is important to safety, and the need for improved ignition system reliability should be examined.

4. The addition of new control devices such as emission controls, automatic speed controls, and steering wheel locking devices introduce new failure modes that should be of concern to vehicle safety.

5. Maintenance-induced errors are suspect as a significant cause of vehicle defects.

Stanford Research Institute (SRI) undertook in-depth investigations of over 100 accidents suspected to be caused by component failures. In-depth investigation was feasible for about one third of them. Some conclusions from the study were: [22]

1. Twenty of fifty case vehicles had been recently serviced, 12 of them within the week of the accident or disablement. Among the 20, seven were brake component failures; seven, tire and wheel failures; three, steering; two, power train; and one, muffler. Such findings suggest that poor servicing is a causal factor.

2. In some cases, the owners either failed to realize that their vehicles were in unsafe operating conditions or decided against having necessary repairs done.

3. Eleven of fifty case vehicles were recently purchased used cars, eight within three months of the accident or disablement.

4. Thirty of fifty SRI case vehicles could be categorized for location of tire and wheel defects by left and right hand side. Twenty-two vehicles showed defects on left side and eight on the right.

Characterization Guidelines. From the review of the cited reports and causal factor data, several guidelines and conclusions were drawn to assist in the characterization of, and subsequent development of, performance specifications for the accident avoidance systems of interest. These findings listed below, recognize that the investigators developing the source data may not have learned how to identify vehicle systems and their performance as either prime or contributory factors in accident causation.

1. The basic design and performance of the braking, steering, and suspension systems in current production vehicles are adequate to cope with the current driving environments. There is no evidence that any one system contributed in any measurable degree to an accident.

2. Individual components of a given system are known to have been produced with defects that produce real or potential system failures. Defect identification and recall programs should result in a diminishing frequency of these causes.

3. Brakes, tires, and steering systems were cited most frequently as contributing to an accident. Indirectly, suspension deficiencies compound any deficiencies in the former systems in normal or emergency performance.

4. Degradation through wear coupled with inadequate or no maintenance were cited frequently as causal factors. The appropriate countermeasures are in (a) increasing the reliability and service life of components, and (b) providing early failure warnings or a diagnostic capability.

5. Designs that provide adequate partial performance (through redundancy) in the event of some component failure will be beneficial in avoiding accidents or reducing their severity. Partial failure performance and redundancy are to be evaluated in terms of additional system complexity and any resulting decrease in reliability or increased maintenance needs.

6. Improved system integrity should be the first performance goal, to be followed by increased performance capability (i.e., stopping distance, anti-skid, etc.).

7. Better vehicle performance is indicated if the vehicle-driver combination as a closed loop system could be defined in deriving the performance specifications. Unfortunately, knowledge of human behavior is a weak link in adopting such an approach. The human reaction to environment and vehicle is highly variable and unpredictable during normal behavior, and becomes more so in panic or emergency situations. The available alternative is in meeting, to the maximum extent possible, known human engineering needs and make the vehicle's response as tolerant or forgiving, as practical, of human error.

Specific Characteristics. The specific values cited in the characterization of the riding and handling systems are achievable within the current state of the art in small production vehicles or attainable within the time frame of interest as evidenced by the ESV programs conducted by offshore car manufacturers.

4.4.3 Crashworthiness

Vehicle Interior

The rationale for characterizing the components in the interior of the RSV is included in these characterization descriptions and the cited references. The data from the accident projections formed the basis for characterizing the impact conditions for which occupant protection levels in the vehicle interior were characterized. The use of this data in characterizing the impact conditions follows.

Figures 4-16, -17, -18 indicate the dependency of societal cost on relative impact speed for the crash modes of interest. Figure 4-16 shows the estimated data for the car-car accident mode (comprising approximately 57% of the total societal costs) in the front, side, and rear collision configurations (here front, side and rear denote societal costs due to injuries and fatalities sustained by a vehicle with front, side or rear damage). It is evident from Figure 4-16 that for frontal impacts, 95% of the associated societal costs fall below a closing velocity of 100 mph. This payoff potential and the previously cited state of the art considerations led to the selection of an upper limit for the vehicle interior design for frontal impacts of 100 mph (50 mph equivalent barrier speed).

For the car-car side impact configuration Figure 4-16 shows that a relative impact speed of 60 mph is required to encompass 95% of the associated societal cost which is well above the current state of the art in crashworthiness design (current restraint systems are very inefficient in the lateral impact mode). The current state of the art for this impact configuration, based on previous ESV work, includes relative impact speeds up to approximately 40 mph. This impact speed range appears to be a reasonable limit for crashworthiness characterization for the vehicle interior in the side impact configuration; it encompasses approximately 80% of the estimated total societal cost.

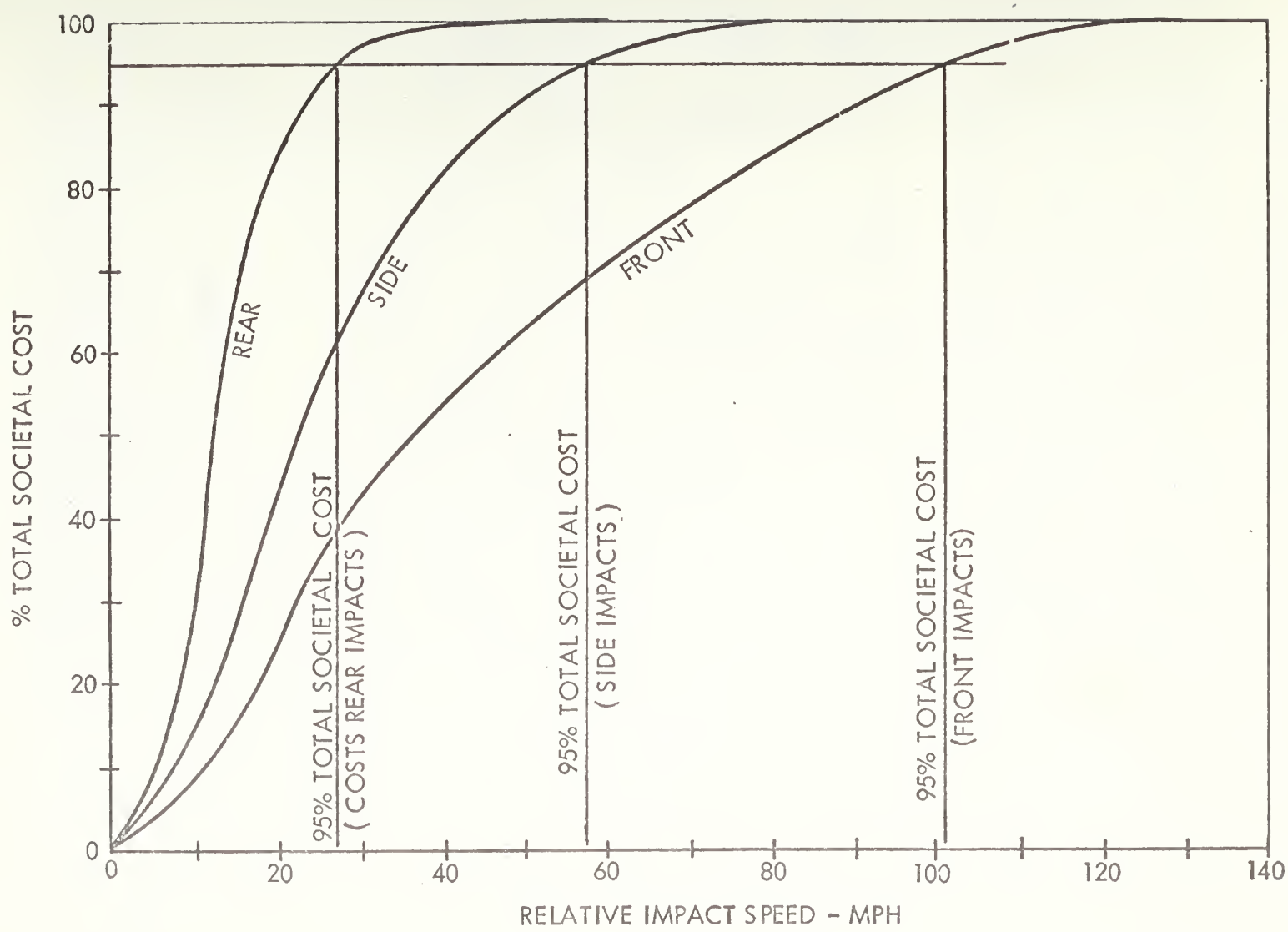


Figure 4-16 Societal Cost Distribution, Vehicle- Vehicle Accidents

For rear impacts, the data in Figure 4-16 shows that 95% of the societal costs associated with this impact configuration fall below a relative impact speed of 30 mph which is well below the current state of the art in crashworthiness design as reflected in previous ESV work. An upper limit of 40 mph, addressing approximately 99% of the rear end accidents (car-car accident mode) appears to be well within the current state of the art and is considered a reasonable design characteristic for the interior.

The dependency of the societal costs on impact speed for car to fixed object impacts, shown in Figure 4-17, indicates that this impact mode is much more severe (the relative impact speed here is the equivalent barrier speed) than the car-car accident mode and appears as the constraining mode for interior crashworthiness design. However, Table 4-1 shows that the total societal cost for this impact mode is less than 1/3 of the societal cost associated with the car-car mode. Since a balanced set of characteristic impact speeds for both the car to car and car to fixed object modes is not readily determinable, specific characteristics for the latter mode were not presented. The approach taken was to characterize an unspecified level of protection that would accrue to the RSV in a fixed object collision based on the crashworthiness protection afforded by the specified car to car impact speed levels. Specific design levels for protection in the fixed object collision mode are determinable through analysis of the designs developed for the car to car modes where the greater safety payoff potential is present.

As noted in the characterization of the rollover mode, this event does not occur nearly as frequently as the car-car mode and has a total societal cost of less than 1/10 of the associated cost for car-car accidents. Figure 4-18 showing the societal costs dependency on impact speed, indicates that to eliminate 95% of the associated societal cost for the rollover mode requires a vehicle design effective for impact speeds in excess of 80 mph.

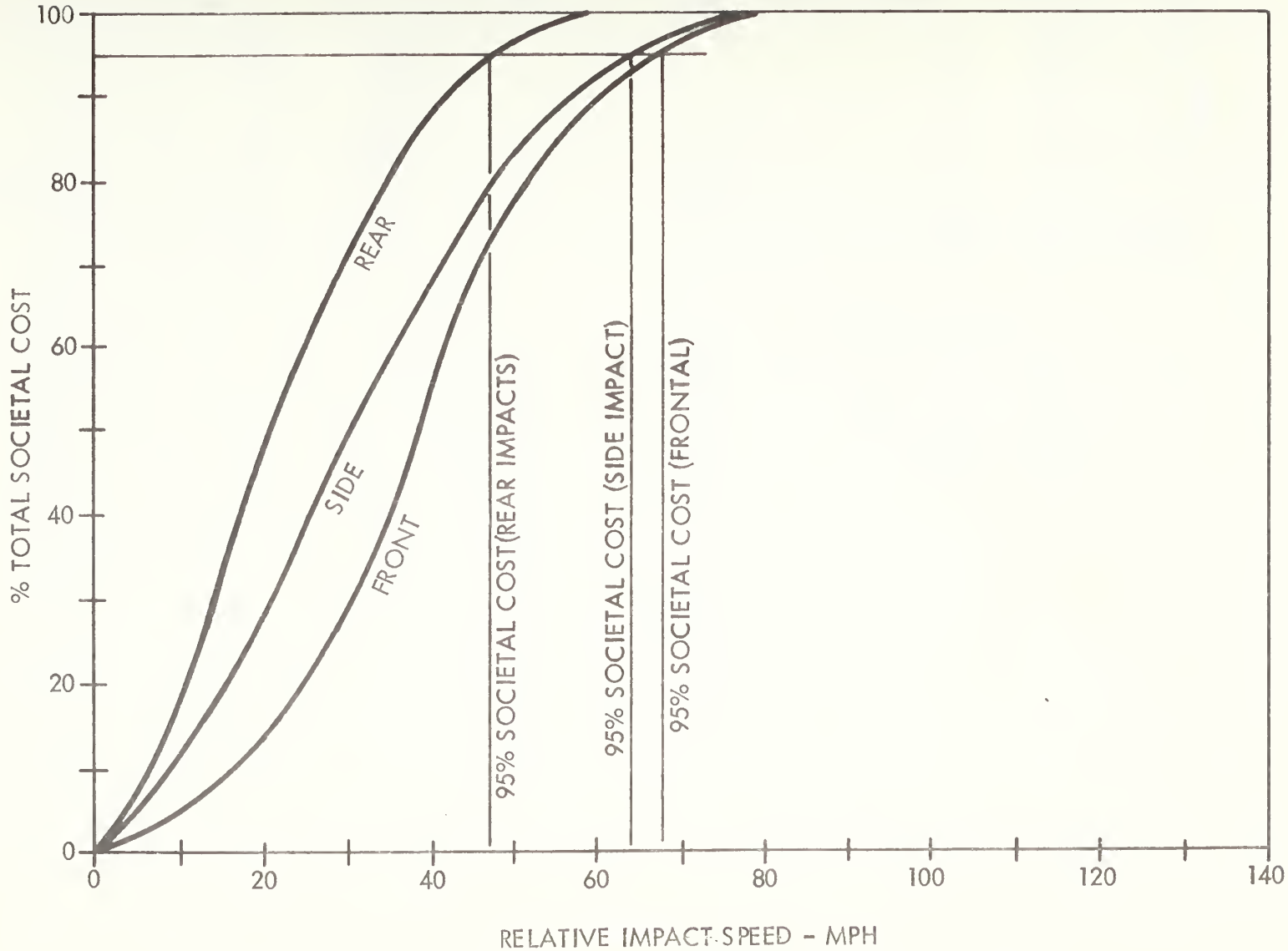


Figure 4-17. Societal Cost Distribution, Vehicle-Fixed Object Accidents

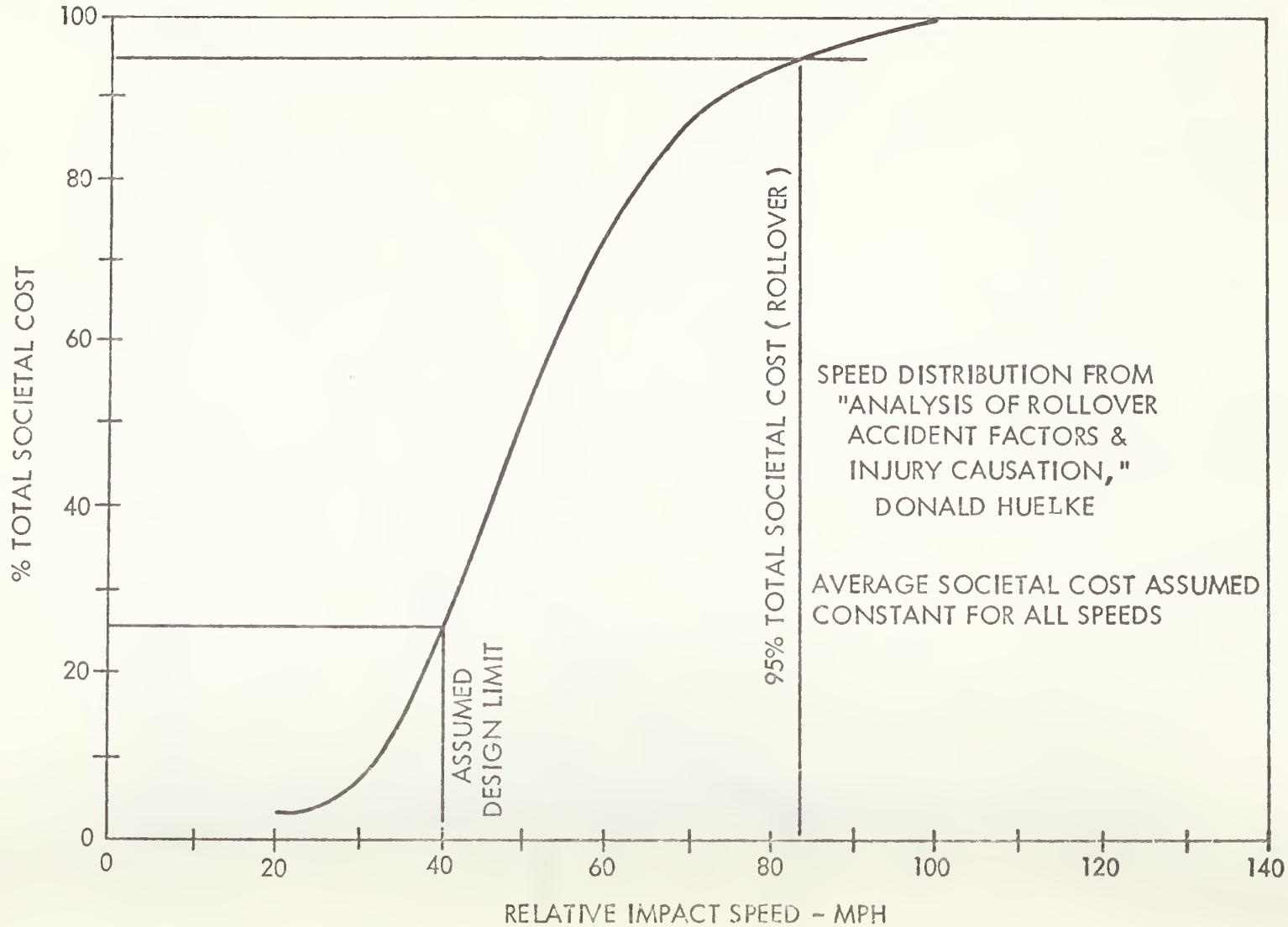


Figure 4-18 Societal Cost Distribution, Rollover

This is well beyond the current state of the art and does not appear to be a feasible design level based on the potential benefit to be gained. There is inadequate test evidence to indicate the feasible levels of protection that can be provided for the rollover. Therefore, a characterization speed of 30 mph was specified as being attainable; the corresponding protection to be afforded the occupant is that defined as injury criteria A in FMVSS 208.

The characterization of ingress-egress features is a recognition of the post-crash problems of quick escape or extrication of vehicle occupants, particularly in those collision events where severe structural damage is experienced. Available accident data is inadequate to describe the relative magnitude of the loss of ingress-egress for the accident modes where such loss and therefore potential benefits of countermeasures cannot be quantified. However, an insight of the basic entrapment problem is provided in some studies to warrant a qualitative characterization. [23,24]

Vehicle Body Structure

The characterization descriptions for this system included basic rationale and the interacting requirements of the body structure with the vehicle interior. The characteristic values were based on previously cited ESV work, which indicates that reasonable restraint performance can be achieved for peak vehicle accelerations of 40 g's and 20 g's for front (and rear) and side impacts respectively.

Vehicle Body Exterior

Table 4-2 summarizes the societal cost per injury (a fatality is included in this composite term as the extreme injury) for the six accident modes considered and indicates the relatively severe nature of the pedestrian and cyclist impact modes. Fortunately, as reflected by the total societal costs associated with these accident modes (see Table 4-1), the rate of

occurrence of these modes is not nearly as high as the less severe impact modes involving injuries within the vehicle interior. Figures 4-19, -20, and -21 show that for the most part (impacts with motorcycles are an exception here), 95% of the societal cost associated with injuries and fatalities involving pedestrians and cyclists fall below a 40 mph impact speed level.

Table 4-2

Summary of Societal Costs for Various Impact Modes*

Impact Mode	Total Societal Costs All Injuries $ Billions	Number of Injuries & Fatalities	Average Cost/Injury
Vehicle-vehicle	18.6	2.391×10^6	$ 7,780
Vehicle-pedestrian	4.5	1.778×10^5	25,310
Vehicle-fixed object	5.1	3.678×10^5	13,870
Rollover	1.7	7.638×10^4	22,260
Vehicle-pedalcycle	1.1	6.047×10^4	18,190
Vehicle-motorcycle	1.9	6.981×10^4	27,220

*Societal cost data from study documented in Section 3.3, Societal Costs and Benefits, Volume II.

The current state of the art in vehicle crashworthiness does not indicate a demonstrated degree of protection to impacted pedestrians and both classes of cyclists. Therefore, qualitative protective characteristics are described based on engineering and design considerations that would mitigate some of the trauma experienced by the impacted individual.

Other possible techniques for external impact protection include the use of retention devices to retain the victim on the vehicle, following impact, for vehicle ride-down. This approach eliminates the hazard of tossing the

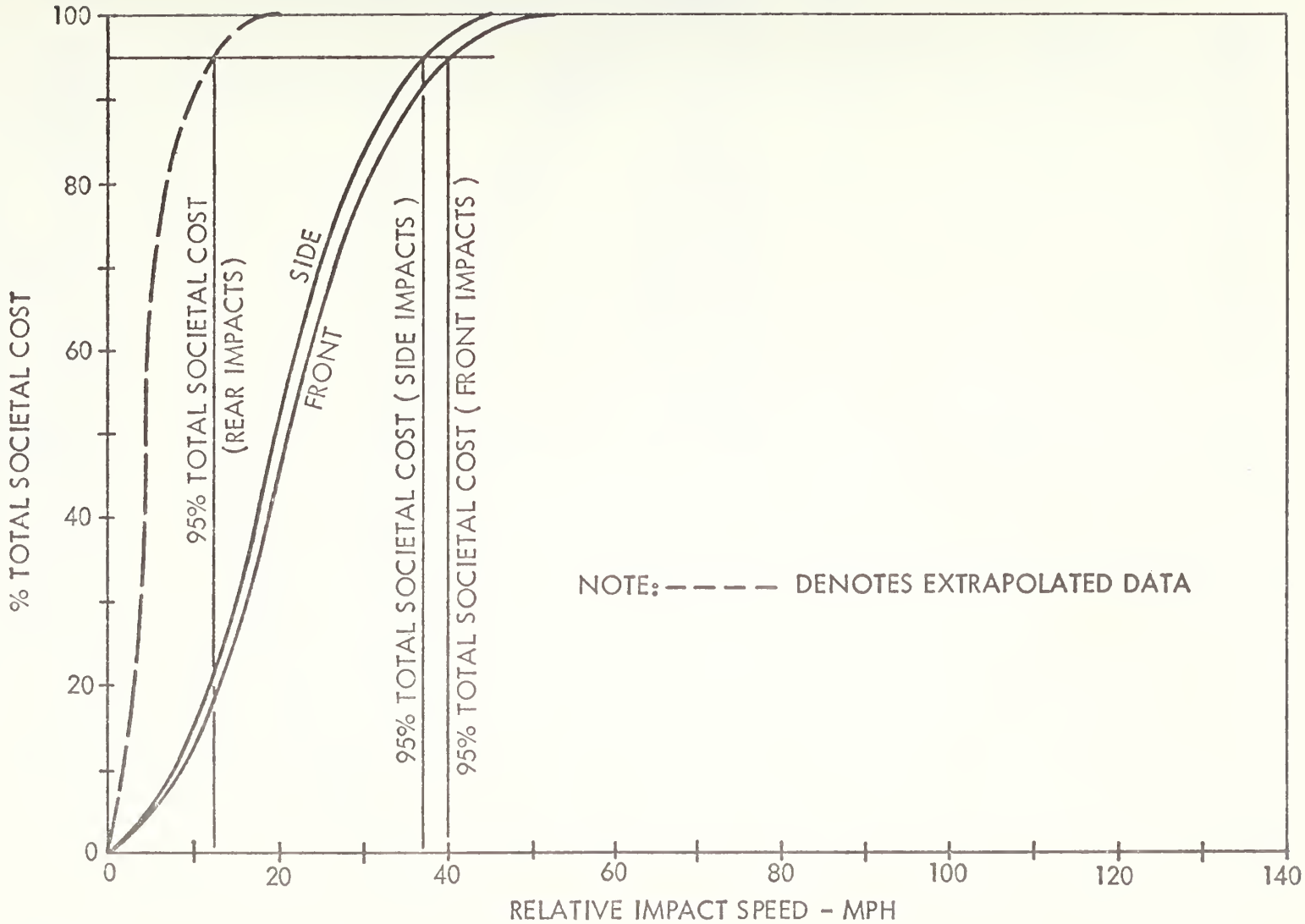


Figure 4-19 Societal Cost Distribution, Vehicle-Pedestrian Accidents

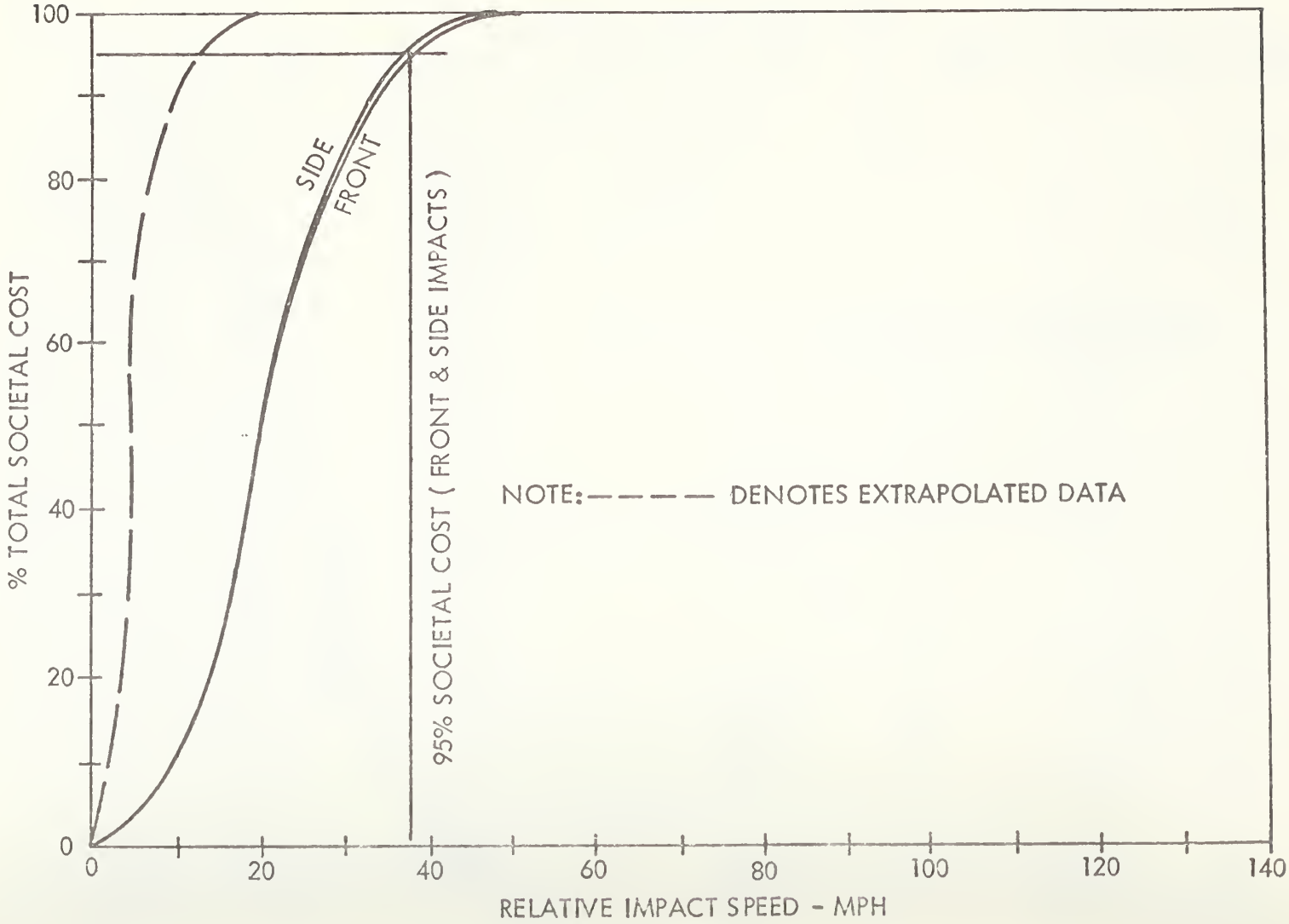


Figure 4-20 Societal Cost Distribution, Vehicle-Pedalcycle Accidents

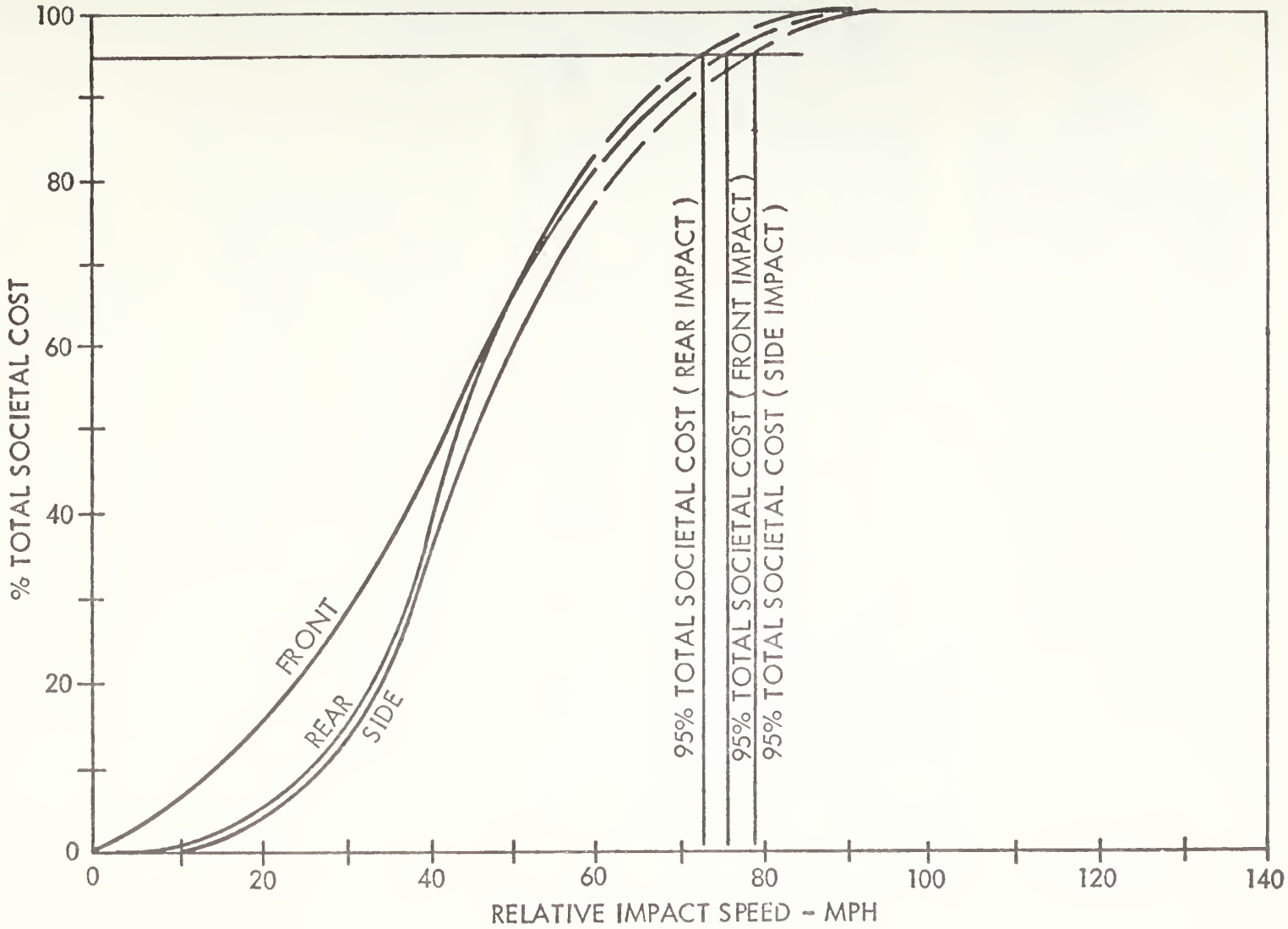


Figure 4-21 Societal Cost Distribution, Vehicle - Motorcycle Accidents

victim into nearby objects and sustaining injuries from secondary impacts, however, this approach is probably effective at the lower impact speeds (under 20 mph) since the total available impact energy is imparted to the victim. This retention approach was not characterized because some of the drawbacks inherent in these devices (possibility of striking, instead of capturing the victim, reliability, integration with the front end structure, weight, costs, etc.) appear to outweigh its potential benefits.

Occupant Restraints

As noted in the discussion on the characterization of these systems, a specific restraint selection for use in the projected accident environment is inappropriate at this time. Such a selection requires the support of cost effectiveness analysis of candidate systems when they are exposed to the impact conditions of interest. Therefore, the restraint system characterizations were limited accordingly.

The minimum level of protection characterized for the RSV restraint system is that specified in FMVSS 208 which appears to be a reasonable lower limit of protection based on prior ESV work. A comparison of the FMVSS 208 protection requirements with prior ESV criteria is presented in Table 4-3.

Table 4-3

Summary of Occupant Protection Requirements
FMVSS 208, Original ESV, Optimized ESV

Criteria	FMVSS 208	Original ESV[b]	Optimized ESV
Injury Requirements			
Ejection	None (c) (No ejection)	None (c) (No ejection)	None (c) (No ejection)
Head Acceleration			
Resultant	HIC ≤ 1000 (a)	80g/3 msec- (d) 100 g max	SI 1000 (f)
Lateral	--	--	40 g
Vertical	--	--	15 g
Chest Acceleration			
Resultant	60g/3 msec	60g/3 msec (e)	60g/3 msec
Lateral	--	--	20 g
Vertical	--	--	15 g
Pelvic Acceleration			
Lateral	--	--	60 g
Vertical	--	--	15 g
Femur Loads	1700 lb	1400 lb	1400 lb

(a) $$HIC = \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a \, d\, t\right]^{2.5} (t_2 - t_1)$$

(b) Includes all changes promulgated during program.

(c) No injury requirements, test dummy shall be contained within outer surfaces of vehicle passenger compartment (windows and doors closed).

(d) Design goals, 20 g for lateral, 15 g for rollover impacts.

(e) 100 g maximum for low-speed impacts.

(f) SAE J885a.

4.4.4 Propulsion System

Current System Characteristics

Predominant vehicle parameters that determine acceleration performance are vehicle weight, power available for acceleration, aerodynamic resistance and rolling road resistance. When comparing various vehicles for performance, it is usually sufficient to consider the vehicle weight/power ratio as the significant parameter. Generally, aerodynamic and rolling resistance (which is directly related to vehicle weight) are secondary parameters and can be ignored for this comparison. The weight/power parameters for both domestic and import cars are shown in Figures 4-22 and -23 for the years 1969 and 1974. The data used here are restricted to sedan type vehicles, each incorporating the smallest engine available. Vehicles over 3600 pounds were not included. The years 1969 and 1974 were chosen for comparison since they will reflect the effect of added emission controls and safety requirements, primarily bumpers.

In the comparison of car weights, the 1969 domestic cars averaged approximately 3000 pounds whereas the imports seem to bunch in two groups, one at 2000 and one at 2900 pounds. In 1974, the domestic cars are averaging a higher weight of approximately 3200 pounds and the import (lightweight cars) average weight groups increased from 2000 to 2200 and from 2900 to 3000 pounds.

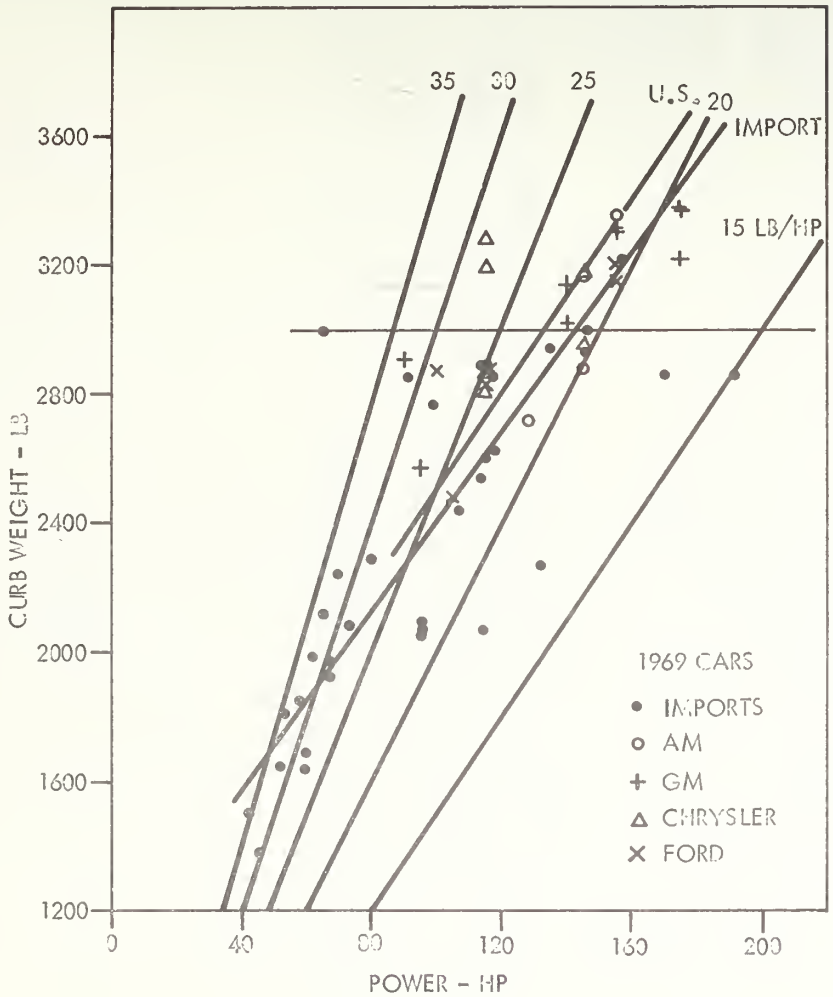


Figure 4-22. 1969 Domestic and Imported Cars

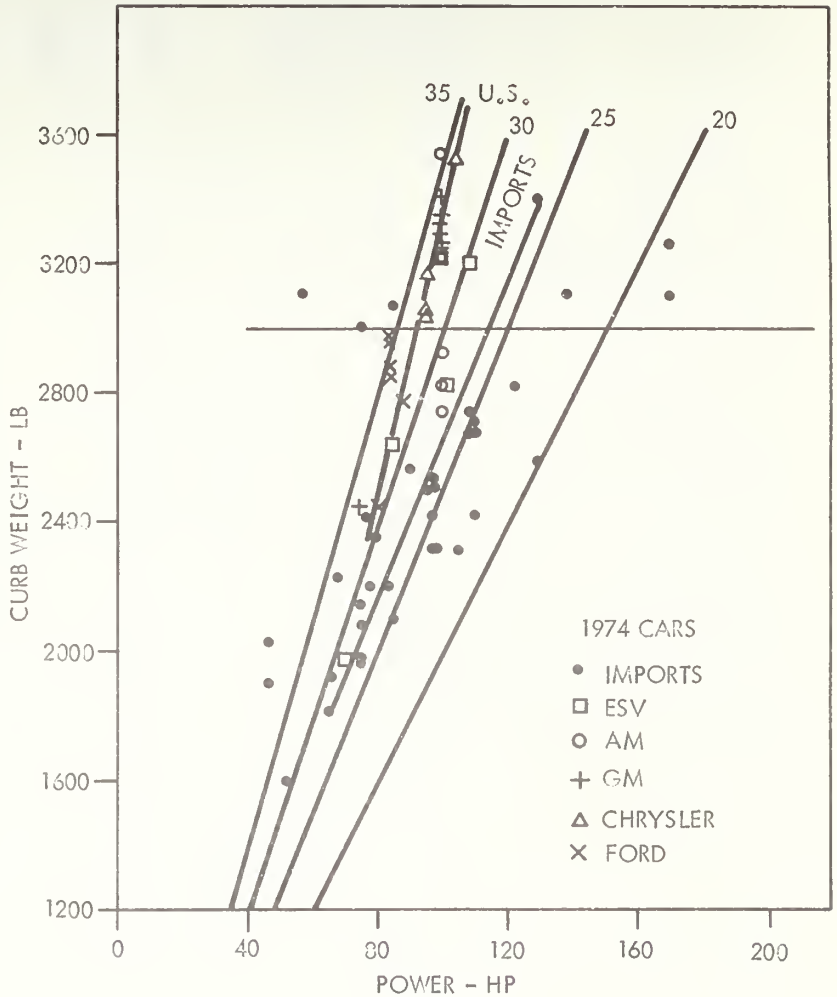


Figure 4-23. 1974 Domestic and Imported Cars

Power comparisons between the years 1969 and 1974 show significant changes. The domestic car in 1969 averaged about 132 hp for a 3000 pound car, and 90 hp for a 3000 hp car in 1974. This gives the performance value of 23 lb/hp weight to power ratio in 1969 and 33 lb/hp in 1974. The imports averaged 142 hp in 1969 and 114 hp in 1974, and respective power ratios of 21 lb/hp and 26 lb/hp for a 3000 pound car. It is interesting to note that the domestic cars decreased in performance value of 43% between 1969 and 1974 while the imports dropped 24% in the same interval.

Also both vehicle weight and power available data points in 1974 are bunched closer than in 1969. This is more evident for domestic cars than for the imports, although both show the same tendency. The 1969 cars performance levels ranged from 19 to 32 lb/hp compared with 22 to 37 lb/hp in 1974, because of the trend to increased vehicle weight and lowered power.

Fuel Economy and Driving Range

Fuel economy tests, as reported by EPA for city driving, have shown the following mileages for all 1974 production vehicles with gasoline engines driven on the federal driving cycle:

Curb Weight, lbs	Mileage, mpg
3000	24
2500	19.5
3000	15

Assuming that these mileages will be improved in the next few years through on-going engine developments, the 1985 ESV should obtain increased city driving mileage of at least 20%, resulting in the following mileage projections:

Curb Weight, lbs	Mileage, mpg
2000	29
2500	23
3000	18

Based on a characteristic driving range of 250 miles for the RSV concepts, the amounts of fuel to be carried in the RSV are:

Curb Weight, lbs	Fuel, gal.
2000	8.6
2500	10.9
3000	13.9

For safe operation, it is desirable that any RSV fuel tank with volatile fuels be as small as possible and located in an area of least penetration or collapse during a crash. The smaller tank minimizes the fire potential during any vehicle structure crushing in an accident mode.

For long trips of steady driving, the mileage would improve to higher values, thereby allowing a greater range than those achieved in the federal driving cycle. For example, mileage can double for a car driven at a steady speed of 40 mph compared to the mileage for the car driven in the federal driving cycle.

Propulsion System State of the Art

A number of alternative power plants may be available for use as the RSV propulsion system in 1985. The ultimate selection of a propulsion system will be based on an analysis of candidate units using an applicable set of evaluation factors. A brief description of the state of the art of power plants that may be candidates for production vehicles in the 1985 time frame follows.

Conventional Gasoline. The conventional spark-ignition piston engine is undergoing intensive upgrading to maintain its competitive edge over other power plants emerging for vehicle use. Improved fuel delivery systems, electronic spark ignition to improve the combustion process, lightweight materials, and increased specific power output should make this engine

very competitive through the 1980's. Variable valve timing features to control intake and exhaust events can result in more efficient throttling of the engine and better control of the exhaust emissions. [25]

The most promising development is the modification of the combustion chamber to allow the burning of lean fuel-air mixtures. The fuel-air mixture is stratified to allow a rich mixture at the ignition point in an auxiliary combustion chamber while maintaining an overall lean mixture in the main combustion chamber. The auxiliary chamber is connected to the main chamber which allows the torch effect of the burning charge in the auxiliary chamber to ignite the lean charge in the main chamber. The Honda CVCC engine, an example of a stratified charge engine, has two intake valves for each combustion chamber. The auxiliary chamber valve admits a rich mixture which is ignited by a spark plug located in this chamber. The burning charge then ignites the very lean charge in the main chamber that has been charged by the other intake valve. An overall lean fuel-air mixture is burned in this manner which produces very low HC, CO and NO_x exhaust emissions. EPA tests of prototype Honda CVCC engines gave the following results: [26]

	Emission Products			
	HC	CO	NO_x	Mileage
	gm/mi	gm/mi	gm/mi	mpg
1948 cc engine low mileage test, 2000 lb weight	.18	2.12	.89	22.1
1948 cc engine 50,000 miles test, 2000 lb weight	.24	1.75	.65	21.3
1948 cc engine low mileage test, 3000 lb weight	.28	3.08	1.56	19.4
1975 Federal Standards	1.5	15.0	3.1	
1977 Federal Standards	1.5	15.0	2.0	

Another type of stratified charge combustion chamber is where the fuel is injected into the chamber and charge stratification takes place in the fuel spray. The fuel is injected near the ignition point into a swirling intake air charge and combustion takes place in the fuel spray similar to a diesel engine combustion. Stratified charge burning takes place in the fuel spray with the rich portion of the fuel near the ignition point and lean burning in the outer reaches of the fuel spray. Examples of this type combustion are the Texaco's TCCP and Ford's PROCO engines. The Texaco engine has had the most development to date. EPA tests have shown the following results for this engine installed in a car [27] with 2750 lb test weight:

Emission Products			
HC	CO	NO_x	Mileage
gm/mi	gm/mi	gm/mi	mpg
.30	.67	.34	15.6

Emissions in the Texaco engine were controlled with the installation of catalytic reactors in the exhaust system and with exhaust gas recirculation. Performance was severely affected by this exhaust gas treatment to obtain low NO_x emissions.

So far, the engine that seems the best choice for emissions reduction without costly exhaust gas treatment is the Honda type dual combustion stratified charge combustion process. Further emission control systems have been applied with some degradation in driveability. GM, Ford, and [28] other automotive manufacturers are actively conducting research on improvements to the stratified charge process, indicating its potential to meet the future demands of low exhaust emissions and high fuel economy with minimum costs.

Rotary Combustion Engine (Wankel). The production Wankel engine is a four-cycle, spark-ignition, rotary displacement, internal combustion engine. Ports are used for intake and exhaust. The combustion chamber shape, the timing of inlet and exhaust events, and the problem of obtaining good sealing between chambers (resulting in poor thermal efficiency) limit the efficiency of this engine over its operating speed range.

The combustion chamber shape produces a mass distribution of the fuel-air mixture that results in a very slow combustion rate allowing burning to take place in the exhaust manifold resulting in heat energy loss. However, the slow combustion plus high exhaust gas temperature do provide a process to reduce exhaust emissions. Retarding the spark timing in a piston engine does the same thing. This higher exhaust gas temperature could cause exhaust valve burning in the piston engine whereas in the Wankel engine, its only ill effect is lower thermal efficiency. The poor sealing between chambers causes lower peak temperature during combustion, thereby causing further losses in thermal efficiency.

Low emissions are not a feature of the current Wankel engine. Its main advantages are its light weight, small size, smooth running, and ability to operate at high speeds.

Brayton Cycle Engine. The open cycle Brayton (gas turbine) engine is a continuous flow, continuous combustion high speed system utilizing aerodynamic compression. It has low exhaust emissions, especially HC and CO, but does not meet the 1977 Federal Standards for NO_x. Due to the [29] low CO concentration and high exhaust volume, catalytic treatment of the exhaust for NO_x reduction does not appear to be feasible. Its other problem is poor fuel economy at part-load operation which is where the passenger car engine operates most of the time. In order to increase its fuel economy, it must operate at higher temperatures, thereby requiring high temperature materials which result in a higher cost engine.

The closed Brayton cycle engine consists of a gas turbine and three heat exchangers. This engine uses an external combustion cycle where the products of combustion heat a working gas which is expanded across a power turbine. Since the heating gas is not part of the working gas, its combustion process can be tailored to give low exhaust emissions.

Stirling Engine. The Stirling engine is an external combustion piston engine utilizing heat transfer of the combustion gas to a light-weight working gas which drives the power piston. Its main design problem is in minimizing the heat transfer losses which requires careful control of the heat passages and heat exchangers. The peak pressures in the working cylinder are kept low which provides quiet engine operation. Its cycle is similar to the closed Brayton cycle, using pistons instead of turbines for expansion of the working medium. It is considered a low emissions engine.

Diesel Engine. The diesel engine has been in use for many years in production vehicles. Its main disadvantages are its heavy weight, high cost and noisy operation. It has good fuel economy and low exhaust emissions, however, its emission levels are higher than those obtained with the stratified charge engine. The results of recent tests of three small diesel automotive engines driven on the federal driving cycle are: [30]

	Emission Products			
	HC gm/mi	CO gm/mi	NO_x gm/mi	Mileage mpg
Peugot 504 Diesel 2100 cc, 4-cyl. engine	3.11	3.42	1.07	25.2
Opel Record Diesel 2100 cc, 4-cyl. engine	.4	1.16	1.34	23.8
Mercedes Benz Diesel 2200 cc, 4-cyl. engine	.37	1.46	1.38	23.6

Rankine Cycle. Rankine cycle engines are currently bulky and inefficient due to the many components required to operate this external combustion system. However, these engines have the capability of meeting the low federal emission standards. The larger engines (160 hp) installed [31,32] in passenger cars have had problems in meeting low NO_x requirements. One 90 hp engine did meet the 1977 federal emission standards, but experienced driveability problems in maintaining the federal driving cycle.

The Rankine cycle engine along with other external combustion engines does have the potential of becoming a promising power plant of the future because of its inherent characteristic of low exhaust emission. A substantial amount of research is being conducted both by private comoanies and government-sponsored agencies to enhance its capabilities. One company has already demonstrated in its laboratory that by operating at a temperature of 1000 degrees Fahrenheit and a pressure of 2000 psi, reasonable fuel economy can be achieved with an engine weight comparable with existing internal combustion engines.

The engine's multi-fuel capability may be a factor in its future utilization in the event of shortfalls of gasoline. The Rankine engine, being composed of discrete components connected by plumbing, provides versatility and good space utilization in a vehicle installation.

A major requirement for the widespread utilization of a steam engine is likely to be the development of an anti-freeze capable of withstanding high temperature operation.

Electric Battery Propulsion. Lead-acid battery powered automobiles have suffered from the very heavy weight of the energy source needed for an adequate driving range between battery rechargings. A lightweight, less bulky battery pack utilizing reasonable cost materials is need before this system can be seriously considered for a passenger car.

The theoretical superiority of nickel-zinc alkaline batteries over [33] the lead-acid batteries has long been recognized. In recent year, the

development of the nickel-zinc battery has shown some promise for automotive use. Figure 4-24 shows the comparison of specific power and specific energy of lead-acid and nickel-zinc batteries. The use of the lighter weight nickel-zinc battery can greatly increase the driving range of a battery powered car. Figure 4-25 shows projected range estimates for various sizes of battery packs in cars driven over the SAE metropolitan driving cycle. A lead-acid battery car with a 1500 pound battery pack will obtain a 54 mile range as compared with a nickel-zinc battery car with 1090 pound battery pack which obtains a 145 mile range. At constant speeds, the cars do better in their cruising ranges as shown in Figure 4-26.

Obviously, the electric battery car has no vehicle exhaust emissions. However, if the emissions at the electrical generating power plant are considered, then the additional power generated for electrical vehicle charging produces additional emissions at the generating plant. It is estimated that the additional pollution resulting from fossil fueled generating plants located in urban areas will equal the pollutants from any replaced gasoline powered cars operating within the 1977 federal exhaust emission limits. Alternative generation approaches (nuclear or remote area power plants) are indicated to result in a net pollution reduction if electric battery propulsion becomes widespread.

Hybrid Electric Propulsion. A small heat engine providing electrical charging of a battery system to power an electric drive train is a compromise to reduce battery pack weight. Both parallel and series power paths for the heat engine have been used. A series hybrid system would provide the lowest exhaust emissions unit but with less driveline efficiency than the parallel hybrid. The latter hybrid system provides a direct drive line for the heat engine to the road and a source for battery charging. In either case, with current designs, the pollution levels are not reduced significantly to warrant the expense of the two power sources in the hybrid system. [34]

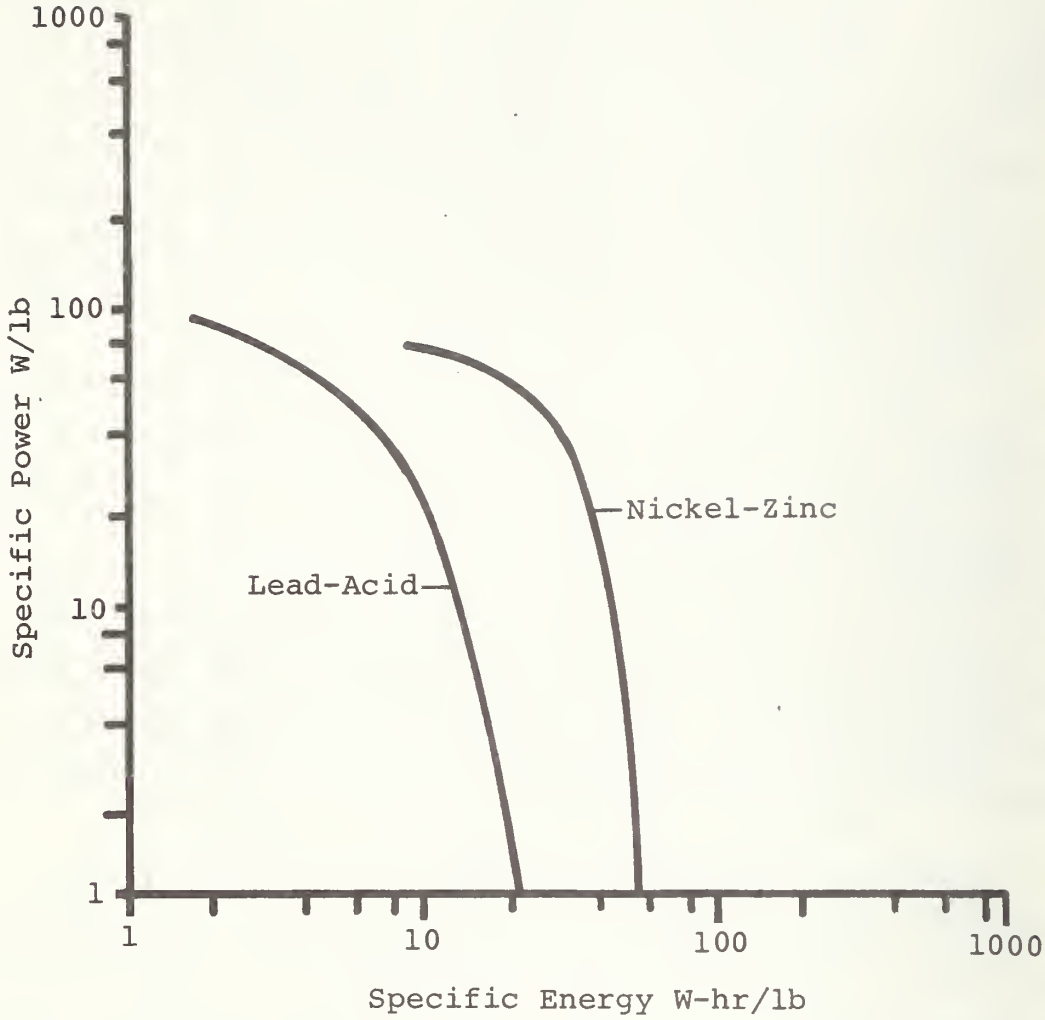


Figure 4-24 Specific Power vs Specific Energy Projected for Lead-Acid and Nickel-Zinc Batteries

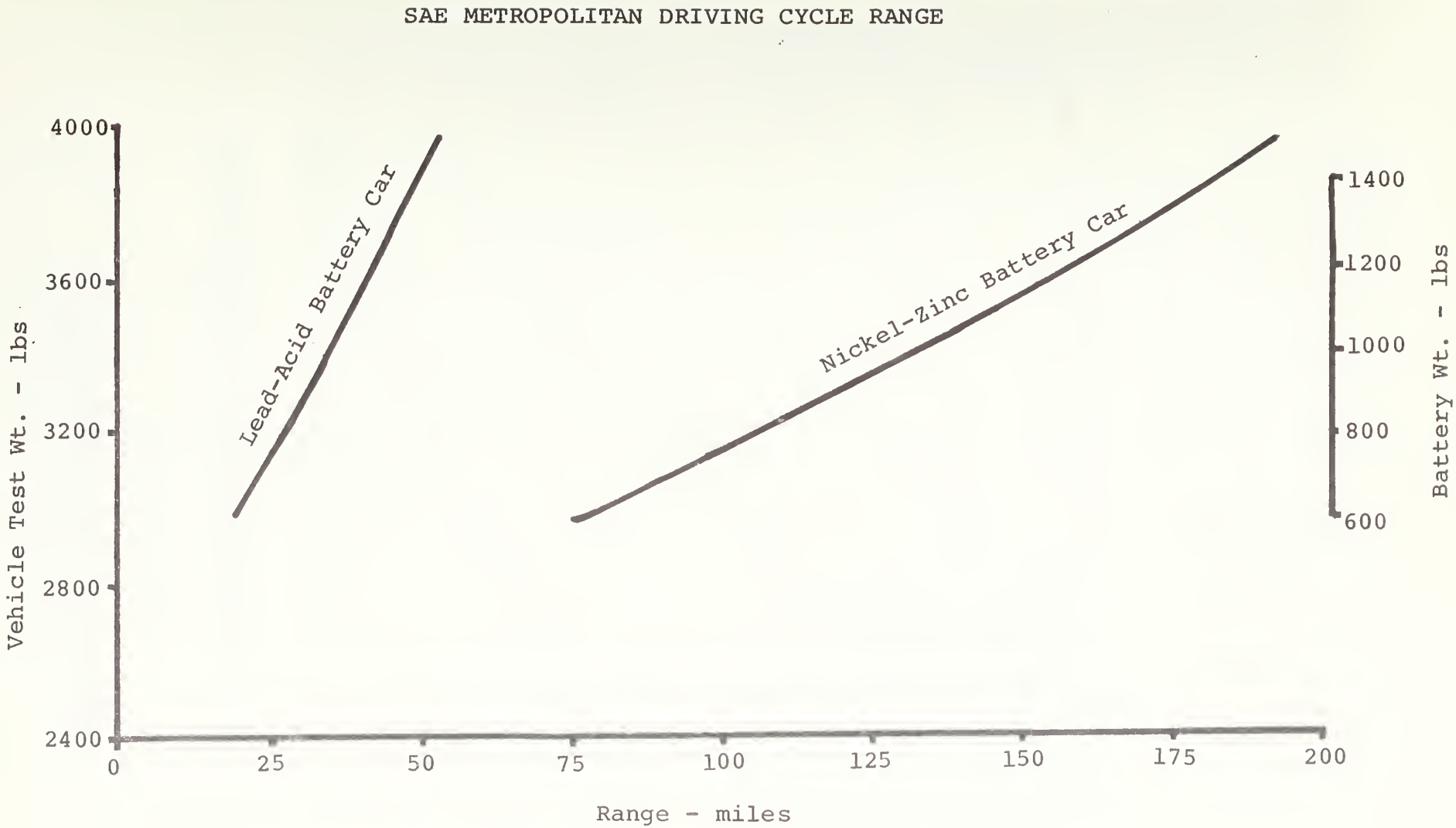


Figure 4-25. Estimates of Electric Vehicle Range with Various Battery Packs for the Lead-Acid and Nickel-Zinc Battery Powered Vehicles.

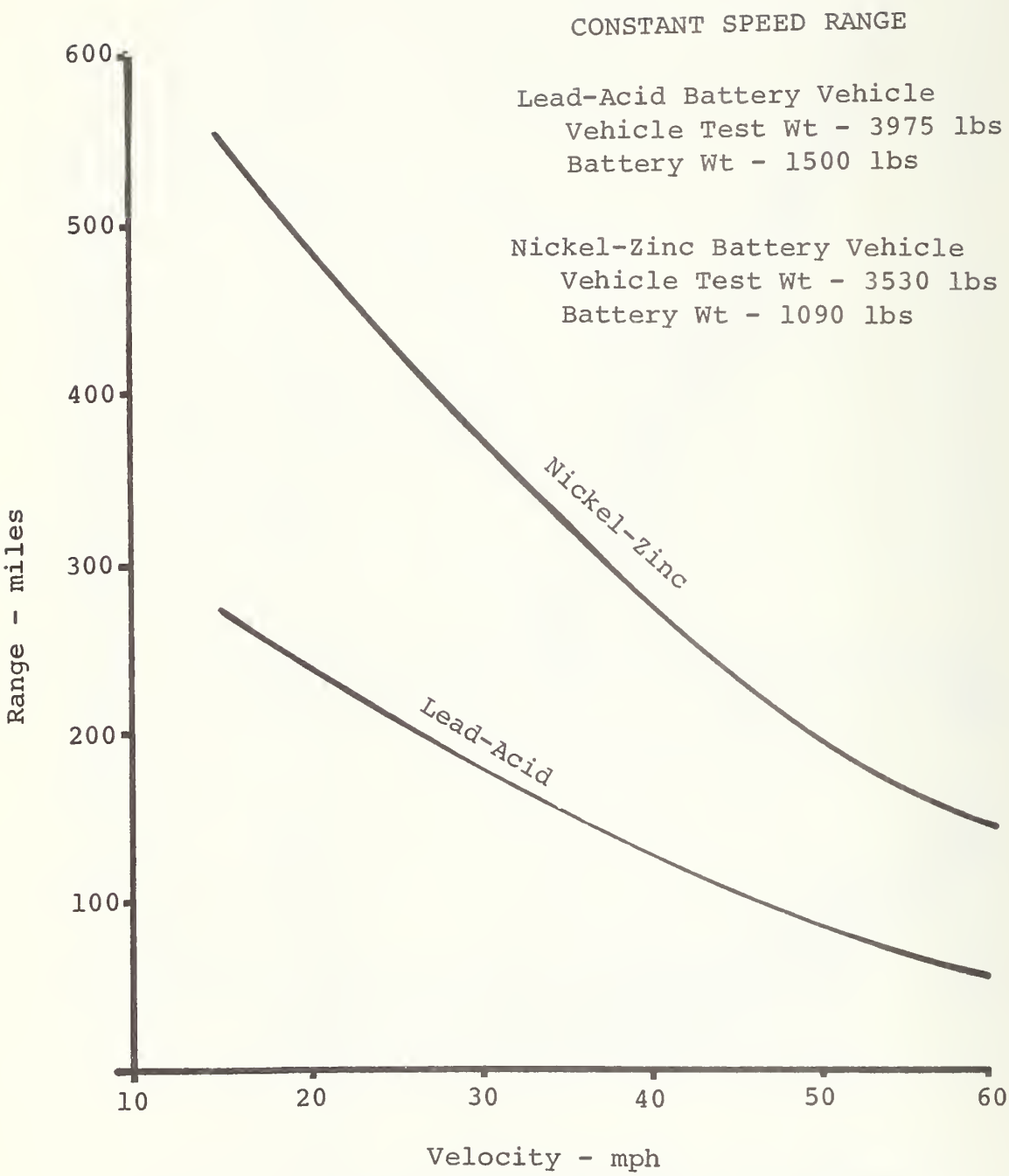


Figure 4-26. Estimated Vehicle Range for Selected Battery Powered Vehicles at Constant Speed Operation

Flywheel Electric Propulsion. A flywheel is a highly efficient power source, but needs an infinitely variable transmission with a high ratio drive line. An electric drive between the flywheel and driving wheel made of a generator-motor combination seems to be the most practical drive train. This system is still in R&D phases.

4.4.5 Accessories

The selection of the major accessories for the RSV was based on their functional use (i.e., driver and occupant comfort, safety, and convenience) while the characteristics of these accessories were governed by considerations of minimum weight and fuel economy. Two of the major accessory items, specifically considered as optional equipment and not installed in the RSV, are the automatic transmission and the air conditioner. In a typical intermediate class car operating on an urban driving cycle (similar to the federal cycle), these two items use 1.6 and 1.5 mpg respectively. Admittedly, though the fuel loss in an RSV class would be lower than these values, the relative penalty of fuel use and added weight remains.

4.5 USE OF RSV CHARACTERIZATIONS

The introduction to Section 4, Vehicle Characterization, noting the overall traffic environment projected for the mid-1980's, did not identify any essentially discrete traffic sub-environments which would make the use of a single, common automobile concept impractical. Rather, the projections anticipate an accelerated evolution of current production passenger car designs into the mid-80 models that conform with national needs to conserve energy, material, and economic resources and to preserve environmental air quality. The characterized RSV's, therefore, reflect two basic automobile concepts (and the permissible subsystems within the concepts) that are appropriate for the projected usage and traffic environments.

Based on the usage projections, the 4-passenger RSV concept was considered to have the larger market and use potential in the mid-1980's and was therefore selected as the basic type of automobile for which a set of recommended performance specifications was developed. These specifications are the subject of the next section, Section 5.

The specific features characterized for the 4-passenger RSV concept will provide a starting point for subsequent design and development of an RSV that complies with the recommended specifications.

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SECTION 5
RSV TECHNICAL PERFORMANCE SPECIFICATIONS

5.0 INTRODUCTION

The recommended specifications for a Research Safety Vehicle (RSV) and the rationale used in their development are presented in this section. The specifications, performance rather than design oriented, are based on the usage and accident environments projected for the United States in the mid-1980's and within which the RSV is to operate.

While some preliminary design analyses were conducted in support of the specifications presented herein, they are still considered to be preliminary since the feasibility of attaining all of the specified requirements remains to be demonstrated. The feasibility demonstrations are in the province of Phase II of the RSV program where conforming designs are to be developed, design cost effectiveness estimated and evaluated, and other tests concerned with producibility and marketing considerations applied. The results of these activities are anticipated to provide the additional data deemed necessary to finalize the technical performance requirements.

The basic objective in developing the RSV specifications was to associate a need with, or justification for, each requirement. The primary inputs for establishing a need were obtained from the findings of the usage and accident studies and projections presented in Section 3.0, Program Definition Foundation.

Accident environment projections established the relationships between the variables and characteristics of the specific accident categories of interest on a nationwide basis. Estimates of societal costs associated with each accident class and for the variables within each class establish priority rankings in terms of societal costs incurred. From this data, the appropriate levels of crashworthiness performance and occupant

protection were established. These need levels are those that have the potential of providing the maximum safety payoffs (benefits) if feasible and cost effective designs can be developed to meet the specified levels. Accordingly, the levels presently specified, even though they reflect prior and current findings in safety vehicle developments, are subject to further updating. It should be noted that specification updating requirements may not arise solely from RSV program activities; it is anticipated that changing national economic and resource conditions or legislation may have a significant influence in the near future on the specifications presented herein. Indeed, the recently announced intentions of some segments of the U.S. automobile industry to significantly reduce the weight of production cars by the end of this decade required a re-estimate of the projected vehicle mix for the mid-80's. The implications of these intentions, if they are realized, on the aggressivity requirements for the various vehicle weight classes in the projected traffic environment are obvious.

Accident data as currently gathered does not provide an insight into the relationships between the performance of accident avoidance systems and accident involvement or prevention. Gross data on certain vehicle systems as primary or contributory factors in accident causation is available as are studies of improved or advanced accident avoidance system performance; the latter rearely addressing the benefits to be drived in accident reduction. Unlike the crashworthiness and occupant protection systems, the specifications for accident avoidance systems are based primarily on considerations of human factors and functional performance rather than accident data. All of the causal accident studies indicate that the human factor is the dominant cause of accidents arising from a multiplicity of driver faults, e.g., distractions, inattention, alcohol, drugs, fatigue, etc. While some of these faults may be amenable to long term countermeasures, a continuing need will exist to make the RSV and its counterparts as forgiving as possible of driver faults and errors in all phases of the usage and accident environment.

The recommended specifications presented in Section 5.1 follow the same format as that of the DOT Technical Specifications, U.S. Intermediate ESV, dated February 16, 1973, so that cross-references of subjects between the two specifications can utilize the same section numbers. Since the DOT specification was used as a guideline, not only for scope and comprehensiveness, but for technical data which reflects a considerable body of prior studies, it is included as an appendix to Section 5 for reference purposes. Each individual specification in Section 5.1 is supported in Section 5.2 by the rationale used in its formulation. This procedure is intended to preserve traceability of the recommended specifications to the original source data.

5.1 PERFORMANCE SPECIFICATIONS

TECHNICAL SPECIFICATION

U.S. RESEARCH SAFETY VEHICLE (RSV)

1.0 GENERAL DESIGN REQUIREMENTS

1.1 OBJECTIVES

The usage environment projected for the mid-80's indicates that the automobile will still be the predominant mode of transportation in the United States, and automotive designs, because of their high capital investments and long lead times, will continue to develop in an evolutionary manner. However, this design evolution will be constrained by national energy conservation programs, either voluntary or legislated, anticipated to be in effect throughout the 1980 decade.

The present U.S. growth rate for energy is 4 to 5 percent annually. In order to bring energy demand into balance with the domestic energy supply over the next decade, an estimated 50% reduction in the annual growth rate is required while new energy sources are being developed. From 1950 through 1970, the imbalance was made up primarily by crude oil imports from the mid-East at prices which showed virtually no increases in this period and which were below North American source prices. Since 1973, and primarily since October 1973, the basic prices of oil imports have increased to

approximately seven times the earlier levels. The consequences of the pricing policies of oil exporting countries are reflected not only in a doubling of gasoline prices but in universal price increases in all sectors of the energy-intensive U.S. economy.

The implications of demand limiting national energy policies on the RSV and its contemporaries in the mid-80's include:

- Lowered utilization of energy intensive materials and processes in production automobiles.
- Lowered fuel consumption.
- Increased operational life.

here the parent ESV program had the primary objective and goal of providing high levels of crashworthiness and occupant protection for the ESV weight class, the RSV objectives and goals must encompass the additional constraint of resource limitations. Accordingly, the specifications that are presented in the subsequent sections address the total RSV system in terms of safety performance and resource conservation considerations.

1.2 VEHICLE DESCRIPTION

The general external and interior configurations of the vehicle shall conform with the following requirements:

Body Style	Sedan, 2- or 4-door
Size Classification	Subcompact
Curb Weight*	3,000 pounds max.

*As defined in Part 571.3(b), Motor Vehicle Safety Standards, United States Code of Federal Regulations.

Capacity	4 passengers

The car shall accommodate, as a minimum, the following physical size range of occupants in the seating positions indicated:

Front Compartment:	5th percentile female through 95th percentile male.
Rear Compartment:	5th percentile female through 50th percentile male.

Exterior Dimensions

The exterior car and body dimensions shall be compatible with the specified body style, capacity, and curb weight.

The manufacturer shall specify these dimensions in the appropriate sections of MVMA-40A Specification Form, Passenger Car.

Interior Dimensions

The interior car and body dimensions shall be compatible with the specified body style, capacity, occupant size and curb weight.

The manufacturer shall specify these dimensions in the appropriate sections of MVMA-40A Specification Form, Passenger Car.

Luggage Compartment

The usable luggage capacity shall be compatible with the specified body style, capacity, and curb weight.

The manufacturer shall specify compartment dimensions in the appropriate section of MVMA-40A Specification Form, Passenger Car.

2.0 SAFETY PERFORMANCE REQUIREMENTS

The specifications for safety performance address all the vehicle systems and subsystems that contribute to the RSV's accident avoidance capabilities, and in the event of an accident, to the protection of its occupants and any other involved participants. While each system and subsystem is specified in terms of its functional performance in avoiding accidents or mitigating accident consequences, there is the implied requirement for balanced performance of the total system in all its functions.

In those instances where the specified performance requirements or conditions for measuring performance differ from existing or proposed FMVSS's, the differences are attributable to the usage and accident environments projected for the mid-80's and to the research data required on a production vehicle concept that is to operate in those environments. Where there are differences, this specification shall take precedence.

2.1 VEHICLE HANDLING AND STABILITY SYSTEMS

The specifications, under this heading, establish the accident avoidance performance of the systems associated with the vehicle's driving dynamics. Unless otherwise specified, all performance tests involving vehicle dynamics will be conducted on a surface with a skid number of 70 to 80 and by a skilled test driver. The vehicle shall be loaded to simulate a front occupancy load consisting of 95th percentile males in the driver and right passenger positions and a luggage allowance of 30 lbs each in the trunk compartment, and its tires inflated to the specified pressure.

These specifications define the test conditions, values, curve shapes, limiting envelopes, etc., for determining compliance with the safety specifications related to the vehicle's dynamic performance.

2.1.1 Braking Performance

Service Brakes

Straight Line Braking. The vehicle, in both a 100% of rated load condition and in a lightly loaded* condition, shall be capable of decelerating to a stop in a distance of 160 feet (24.2 ft/sec^2) from a steady state speed of 88 ft/sec (60 mph). This performance shall be accomplished without two

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*Lightly loaded, per FMVSS 105a, is defined as the unloaded vehicle weight plus 300 pounds (including driver and instrumentation).

wheels on any axle locking up and without deviation from a 12 foot wide lane. In performance tests involving the 100% of rated load and the lightly loaded conditions, the loads shall be distributed in the vehicle so as to simulate the weight and location of occupants and their luggage as specified in 1.2, Vehicle Description.

Braking in a Turn. With the same load conditions as above, the vehicle shall be capable of decelerating to a stop in a distance of 80 feet (21.5 ft/sec^2) without two wheels on any axle locking up or deviating from a 12 foot wide lane from a steady state speed of 58.7 ft/sec (40 mph) on a radius of 357' (producing 0.3 g lateral acceleration). Steering inputs up to 180° are allowed with the rate of steering input not to exceed 500 deg/sec.

In accomplishing the performance specified above, the pedal force shall fall between lines 1 and 2 on Figure I.

Braking on Split-Coefficient Surface. With the same load conditions as in straight line braking, the vehicle shall be capable of decelerating to a stop from a steady state speed of 58.7 ft/sec (40 mph), within a distance of 134 feet (12.88 ft/sec^2) when traveling on a split coefficient surface with skid numbers of 80 and 25. The performance is to be accomplished while remaining in the 12 foot wide lane.

In addition, as a minimum, the service brake system will ensure braking performance in accordance with the values specified in Table I, where:

E = Brake system efficiency

F = Tire factor

R = Brake rating

M = Wet to dry performance rating.

Table I. Braking Performance

	E	F	R	M
Normal	80.0	1.25	100.0	-
Single System Failure	60.0	1.25	75.0	-
Booster Failure	64.0	1.25	80.0	-
Wet Pavement	90.0	1.15	103.5	0.95
Minimum Load	90.0	1.25	112.5	-

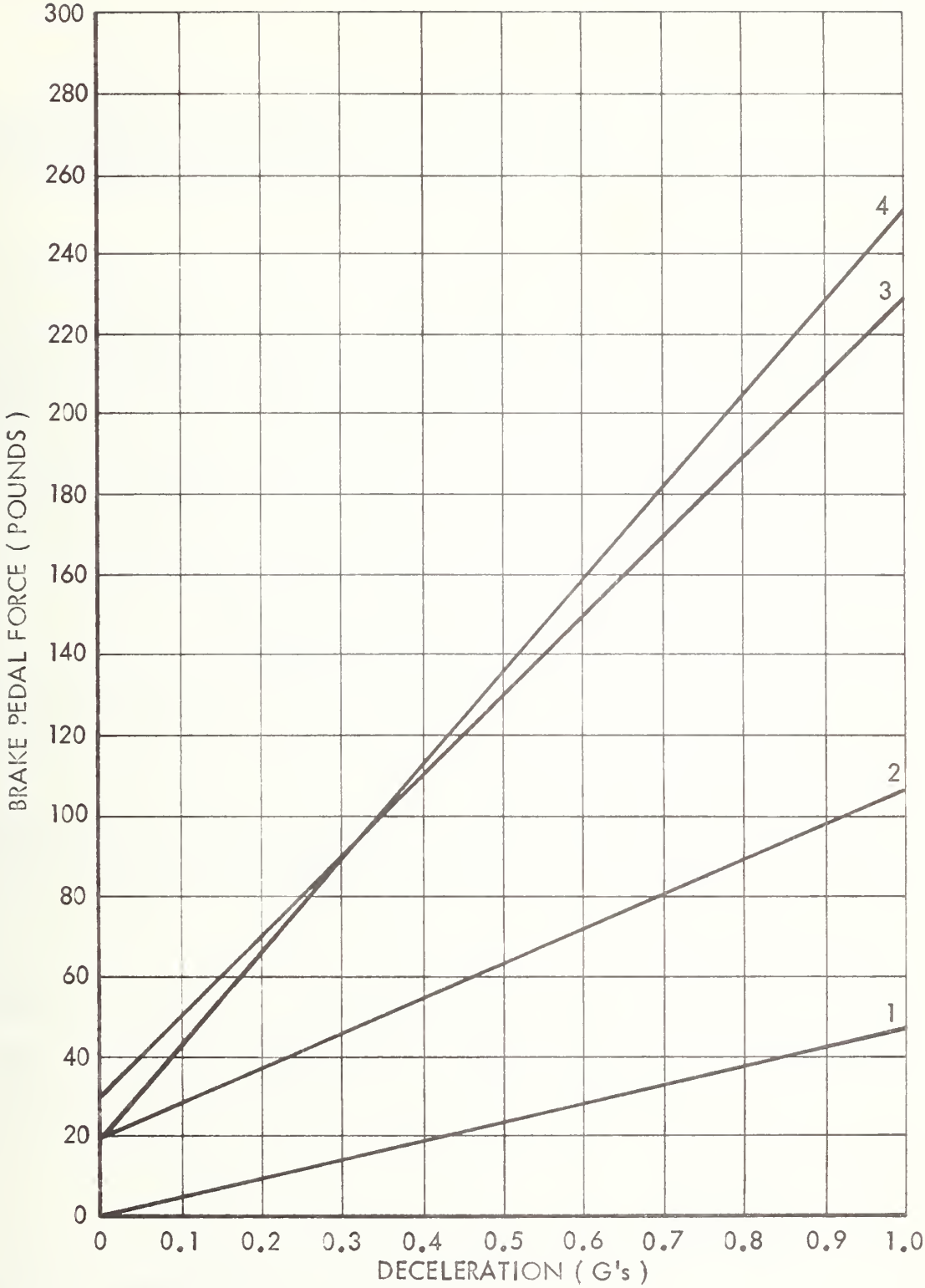

Figure I. Vehicle Deceleration versus Brake Pedal Force

The procedures for calculating the above factors are established in HSRI report, "A Procedure for Evaluating Vehicle Braking Performance" (DOT HS 800 628).

Emergency Brakes

In the event of a booster failure or a leakage type failure of a pressure component of the service brake system, other than a structural failure of a master cylinder, the remaining portion of the service brake system shall continue to operate. With the vehicle at 100% rated load or lightly loaded and a booster failure or partial single failure induced into the system, the pedal pressure shall fall between lines 1 and 3 and lines 1 and 4 respectively in Figure I. Vehicle stopping distances from a steady state speed of 88 ft/sec (60 mph) shall be as follows:

Failure	Stopping Distance
Booster Failure	200 ft. 0.60 g at 150 lbs pedal force
Single System Failure	214 ft. 0.56 g at 150 lbs pedal force

Heat and Water Fade Performance

The heat and water fade recovery performance of the brake system shall be 10% above that specified in FMVSS 105a, January 1, 1976.

Parking Brake

The vehicle, at curb weight and when fully loaded, using a friction type mechanical brake, shall be capable of holding on a 30% grade in the forward and reverse directions. Brake actuation effort shall be less than 90 pounds for a hand-operated system and 125 lbs for a foot-operated system.

Vehicle Jacking

If run-flat devices are used in the vehicle tires, no vehicle jack is required; however, safe jacking points or areas shall be defined for maintenance purposes. If run-flat devices are not provided, a spare tire and wheel,

and a safe, convenient jack shall be furnished. The minimum acceptable criteria for the jacking subsystem have been published as a proposed FMVSS (Reference 35 FR 17055, November 5, 1970).

2.1.2 Steering

Yaw Response

In response to a steering input for which the lateral acceleration is 0.4 g (± 0.02), the vehicle must:

- Maintain a steady state yaw response at forward speeds of 36.7 ft/sec (25 mph), 55 ft/sec (37.5 mph), 73.3 ft/sec (50 mph), and 102.7 ft/sec (70 mph) within the envelope defined by Figure II. Within this envelope, the specific vehicle response must be concave downward at all points. Similar response curves obtained with different lateral accelerations shall exhibit the same characteristic shapes.
- In relation to the 0.4 g yaw response curve on Figure II coordinates, as lateral acceleration increases from 0.4 g, the yaw response curve shall progressively move downward; as lateral acceleration decreases from 0.4 g, the yaw response curve shall progressively move upward.
- Provide a steady state yaw response at 73.3 ft/sec (50 mph), and 102.7 ft/sec (70 mph) which shall be within the envelope defined by Figure II at 0.4 g ± 0.02 lateral acceleration for the following combined load and tire inflation pressure conditions:
  1. Vehicle at 100% rated load, and
  2. Front tire inflation pressure at 120% of the design value and rear tire inflation pressure at 80% of the design value.

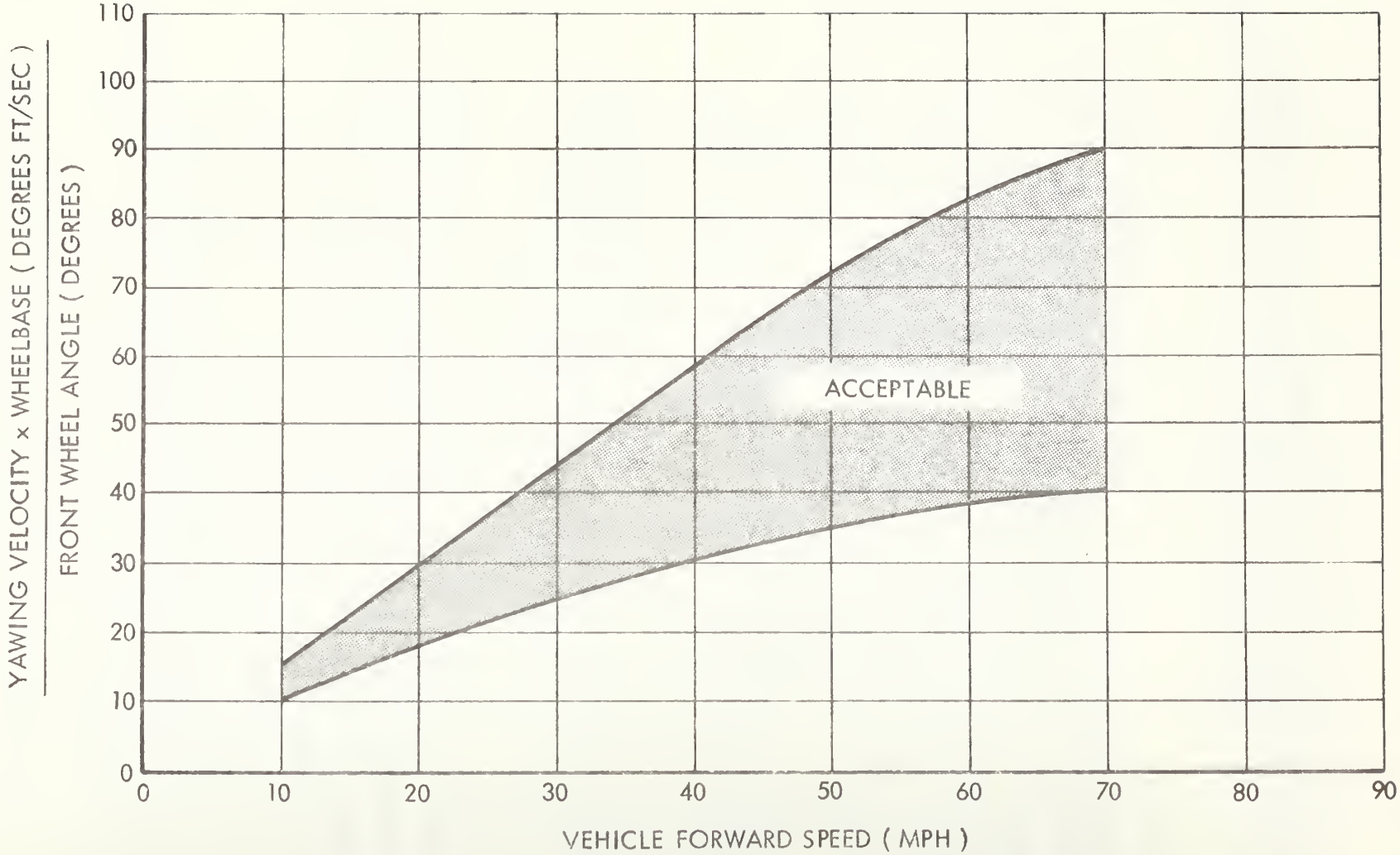

Figure 11. RSV Steady State Yaw Response

- With a steering input applied at a rate no less than 500°/sec and held constant at a value which produces 0.4 g steady state lateral acceleration with test speeds of 36.7 ft/sec (25 mph) and 102.7 ft/sec (70 mph), provide a transient yaw response as described by Figure III. In this figure, the upper curve is the upper limit for a test speed of 102.7 ft/sec while the lower curve is the lower limit for a test speed of 36.7 ft/sec (25 mph) and does not apply to the 102.7 ft/sec (70 mph) test. The initial time, T_o, is the time at which one-half the steering input is complete.

Returnability/Feedback

The vehicle shall be driven at 36.7 ft/sec (25 mph) and 73.3 ft/sec (50 mph) around a fixed radius sized to achieve 0.4 g. At a predetermined point on the vehicle path, the driver shall release the wheel completely and the vehicle must meet the following requirements:

- From a test speed of 73.3 ft/sec (50 mph), the yaw rate, 2 seconds after steering wheel release, must be less than 4 degrees per second. From a test speed of 36.7 ft/sec (25 mph), the yaw rate, 2 seconds after steering wheel release, must be less than one degree per second.
- Show steering wheel returnability stability that falls within the envelope defined by Figure IV. In this figure, curve 1 is the upper bound for response with a test speed of 36.7 ft/sec (25 mph); curve 2 is the upper bound for response with a test speed of 73.3 ft/sec (50 mph); and curve 3 is the lower bound for both.

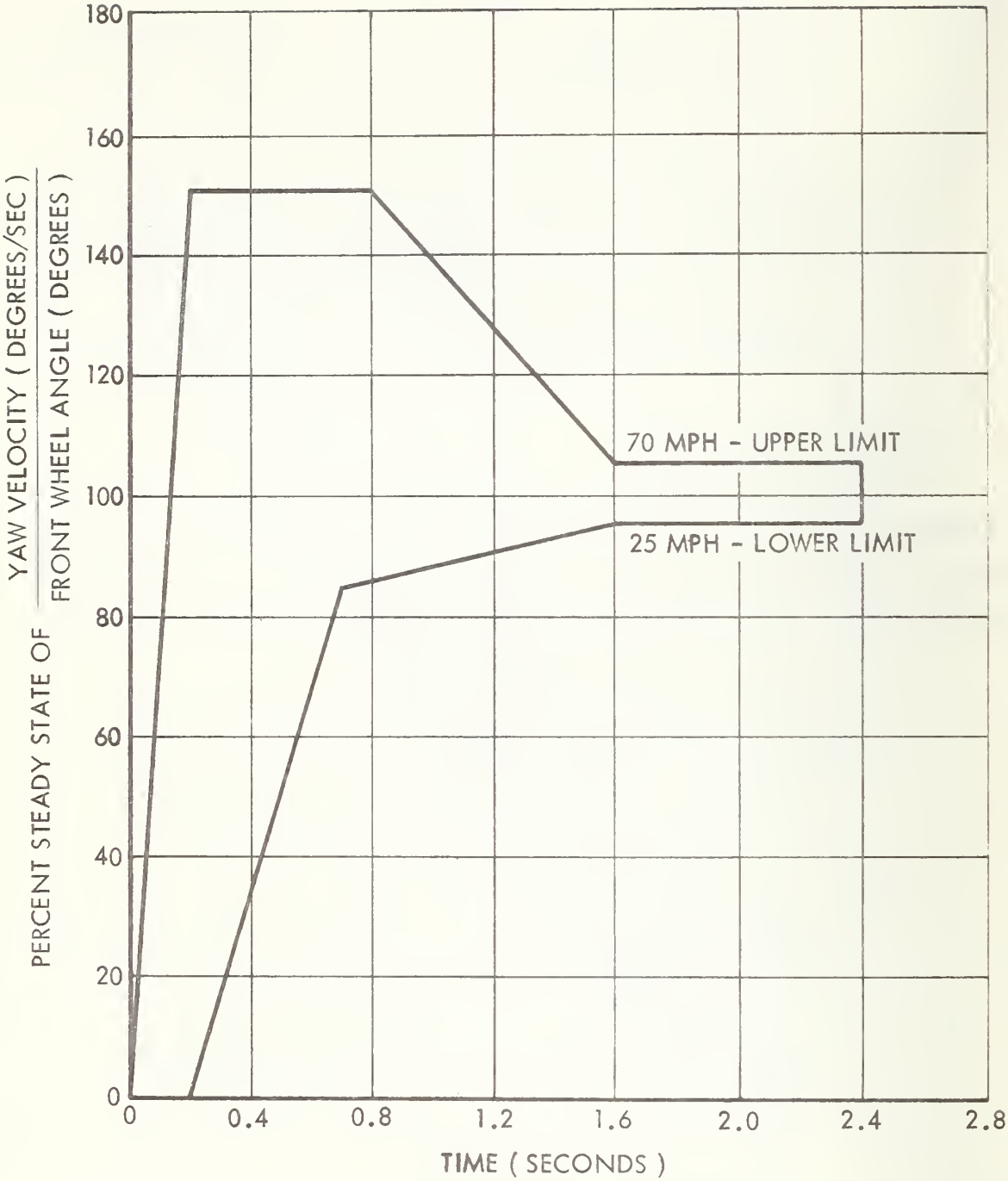

Figure III. RSV Transient Yaw Response versus Time

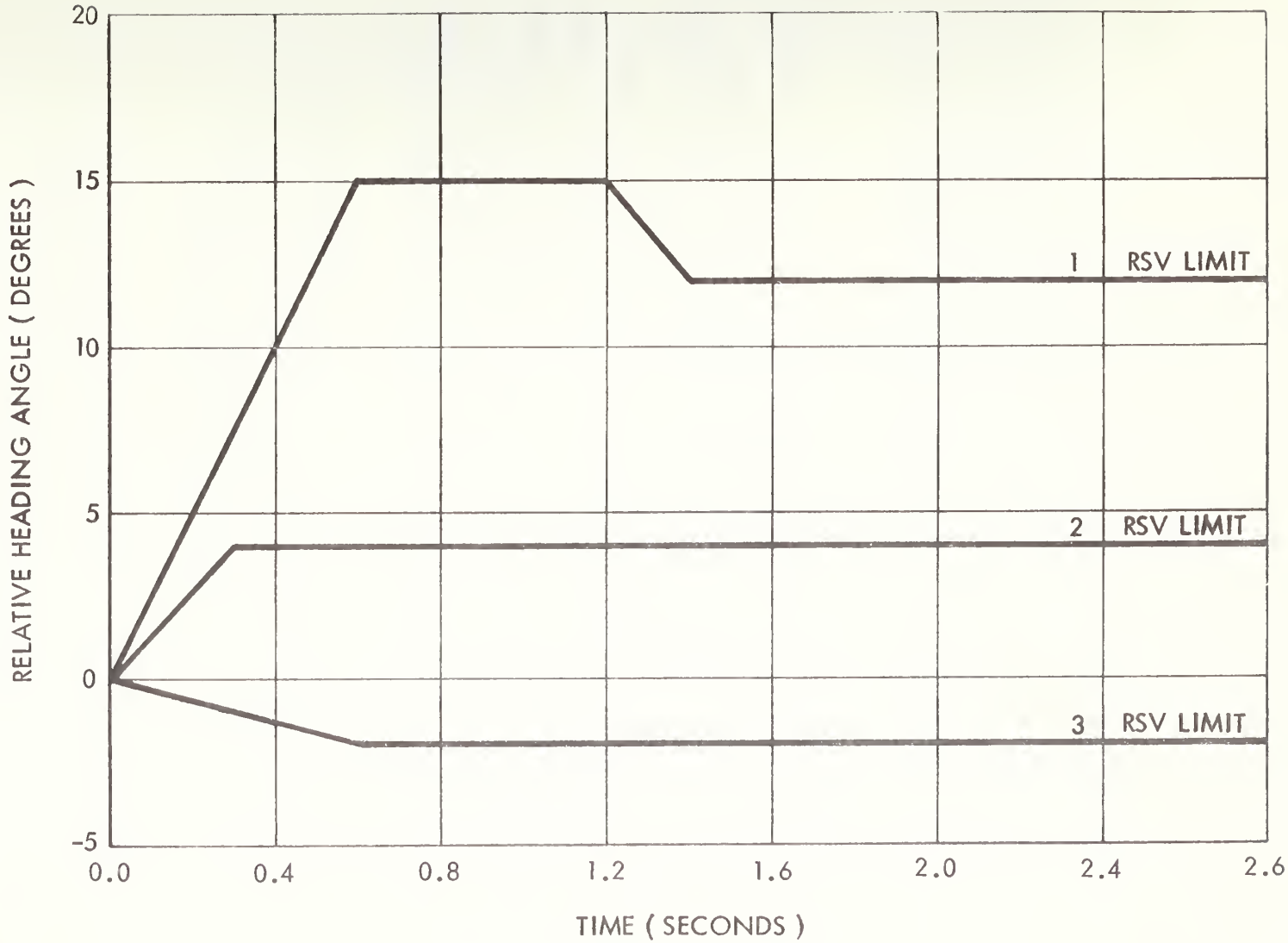

Figure IV. Relative Heading Angles versus Time

2.1.3 Handling

Lateral Acceleration

The vehicle shall, while traveling on a 100-foot radius skid pad at a constant speed, remain stable with lateral accelerations as shown in Table II. A certification circle shall be completed at the required "g" level and a speed tolerance of ± 1 mph with less than 10 degrees total steering wheel movement as the control limit.

Control at Breakaway

The vehicle shall be operated on a skid pad, in a given circular path, at a maximum lateral acceleration until a steady state condition exists. The vehicle speed shall then be gradually increased until any point on the vehicle longitudinal axis within the wheelbase has moved radially outward a distance of 10 feet from the initial path. At this time, the throttle will be closed initiating the test of control at breakaway. Measuring time from the instant the throttle closes, the vehicle must be capable of regaining and following the initial path (plus or minus two feet) within no more than four seconds. This test will be conducted on a steady state circular path of 100 and 225 feet radii.

Other conditions to be adhered to in conducting these tests are:

- No braking shall be performed on the vehicle during recovery.
- Steering wheel movements necessary to regain the original path must not be applied at a rate exceeding 500°/sec.

Directional Stability

This parameter will be verified for the following conditions:

- Crosswind sensitivity
- Steering control sensitivity
- Pavement irregularity

Table II. Lateral Accelerations

SURFACE	TIRE PRESSURE	LATERAL ACCELERATIONS (g)
		FIXED CONTROL
DRY CONCRETE OR ASPHALT	DESIGN VALUE	0.63
	120% DESIGN VALUE	0.62
	80% DESIGN VALUE	0.58
	120% DESIGN FRONT 80% DESIGN REAR	0.65
	80% DESIGN FRONT 120% DESIGN REAR	0.61
WET CONCRETE OR ASPHALT	DESIGN	VALUES TO BE RELATED TO ACTUAL PERFORMANCE ACHIEVED ON DRY SURFACE IN PROPORTION TO WET & DRY TEST SKID NUMBERS.

Tests for these will be run at 44 ft/sec (30 mph), 73.3 ft/sec (50 mph), 102.7 ft/sec (70 mph), and on level pavement with less than 5 mph head-on or tail winds. Specific requirements for each test are as follows:

a. Crosswind Sensitivity - The vehicle shall be subjected to a step function crosswind application of 73.3 ft/sec (50 mph) plus or minus 7.3 ft/sec (5 mph). Total course deviation for a 20-foot exposure shall be measured two seconds after initiating test and shall be less than the value shown in Figure V for the appropriate distance covered by the vehicle in two seconds.

b. Steering Control Sensitivity - The torque required to cause a yaw rate of 2 degrees per second shall exceed 5 inch pounds applied by a steady force at the rim of the standard wheel. If the vehicle is equipped with power steering, then with the power assist inoperative, the torque required at any speed above 5 mph shall not exceed the "power on" torque, at the same steering condition, by more than a factor of three.

c. Pavement Irregularity Sensitivity - The course shall include a semicylindrical solid ridge of one inch radius lying along a line intersecting the directional vector of the vehicle at an angle of 30 degrees. Total allowable course deviation of the vehicle is one foot measured two seconds after ridge contact at speeds between 30 and 70 mph.

2.1.4 Overturning Immunity

To demonstrate overturning immunity, the vehicle in a minimum load condition (driver only) and in a 100% rated load condition shall not overturn under any combinations of braking and/or steering at any speed on a level paved track. As the minimum, the vehicle must not overturn:

- When negotiating a 1,000 ft slalom course at the maximum steady state speed attainable with pylons spaced at 100 ft intervals. A minimum speed of 50 mph is required.

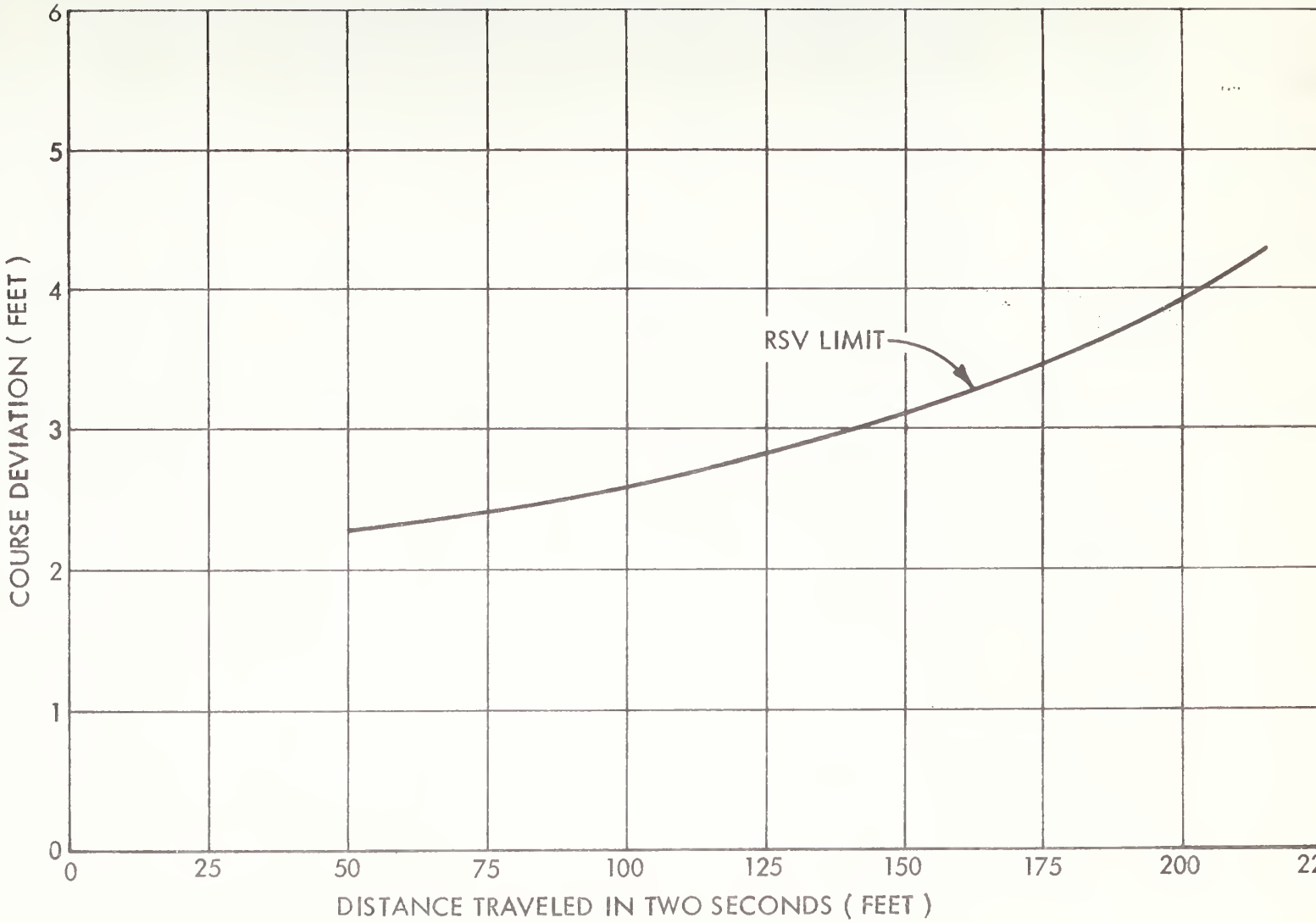

Figure V. Allowable Course Deviation versus Distance Traveled

- When performing the drastic steer and brake* maneuver at initial speeds of 50 and 60 mph.

2.1.5 Power Plant System

The power plant is defined as consisting of a power source which converts duel or energy into mechanical power and a power train which conditions the power and transmits drive torque to the drive wheels and tires. The power plant system shall meet the requirements that follow with the vehicle carrying a payload of 400 lbs.

Acceleration

Adequate power shall be provided to accelerate the vehicle through the velocity ranges and within the times specified below:

0-30 mph in 7 seconds
0-40 mph in 10 seconds
0-60 mph in 20 seconds
30-60 mph in 13 seconds

Power Train

The power train elements and the tires shall be designed to minimize power losses.

Lateral Force Influence

As a minimum, the power output shall remain constant while vehicle travels a 100-foot radius circle at the maximum lateral acceleration under manual control. This performence to be verified for 360° of travel while traveling both clockwise and counterclockwise around the circle.

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*Test procedure for this maneuver is described in, "Vehicle Handling Performance", Vol. I, Highway Safety Research Institute, University of Michigan, November 1972 (DOT HS 800 759).

Fuel Capacity

Sufficient fuel or energy capacity shall be provided for a 250 mile range at a cruising speed of 55 mph.

2.1.6 Ride Performance

The passenger compartment acceleration levels, measured at the seat/passenger interface, shall be below the limits shown in Figure VI, for the indicated range of frequency levels. This performance shall be provided while traveling on:

- Freeways at speeds of 60 to 70 mph
- Rural roads at speeds of 45 to 55 mph
- City roadways at speeds of 25 to 35 mph

2.2 VISIBILITY SYSTEMS

2.2.1 Driver Visibility

The driver's field of view requirements are based upon modifications to published notices of proposed rulemaking: the September 1, 1976, requirements for direct field of view (37 FR 7210) and the January 1, 1974 requirements for indirect visibility (36 FR 1156). The modifications are as follows:

a. Point V_o rather than point M will be used for indirect visibility. If the vehicle is designed to have a very limited range of vision origin points, or a fixed origin point, the point representative of a 50th percentile driver or the single point will replace point V_o for both direct and indirect visibility measurements.

b. In defining zones for direct visibility, all conical surfaces will be replaced by corresponding planar surfaces; e.g., paragraph S 5.8.1 (c) will read "A plane surface containing point V_2 and forming an angle of 11° with the Y plane."

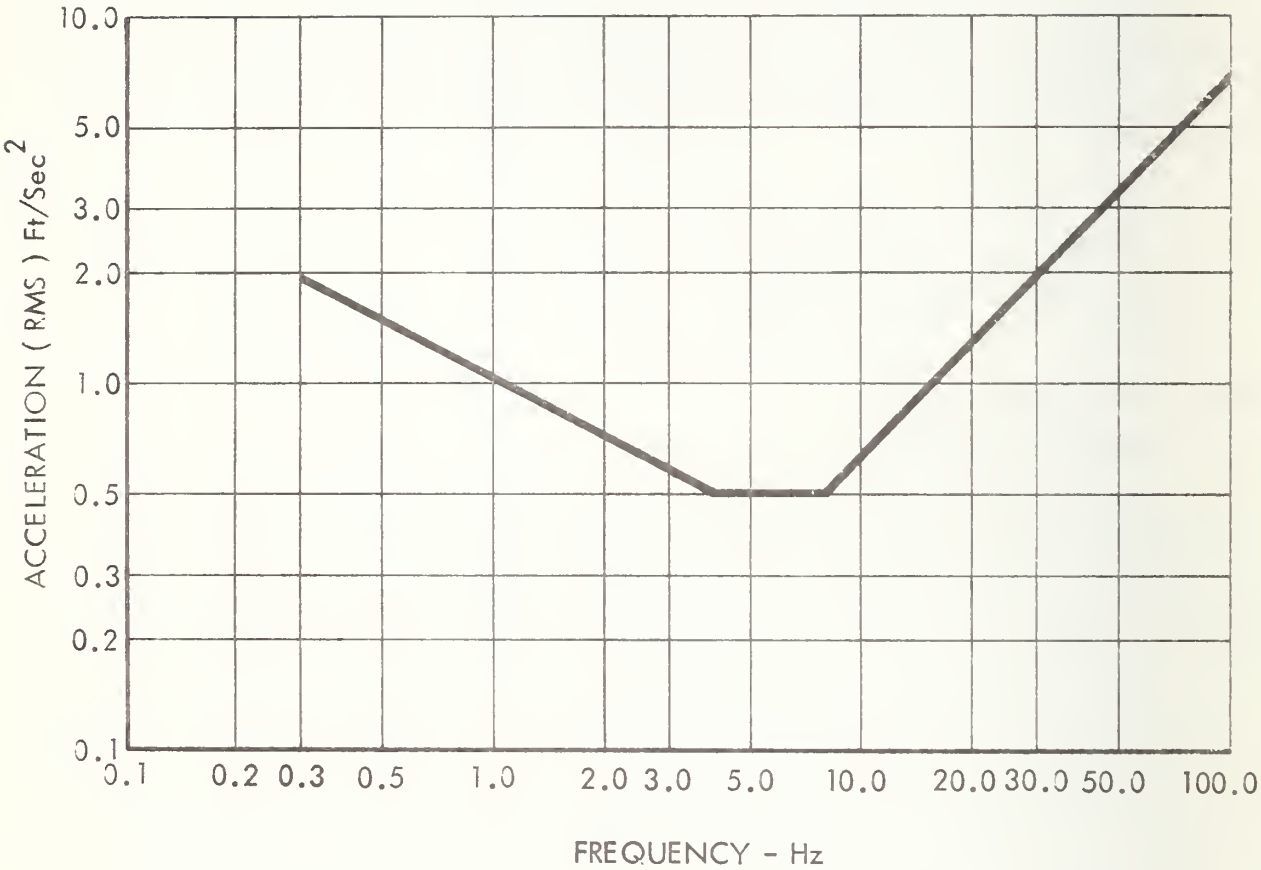


Figure VI. Passenger Compartment Accelerations versus Frequencies

c. Zone I (ref. paragraph S 5.8.1(a) and (b)) is modified from 17° left and right of the X plane to 15° left and right of the X plane. Zones II and III are expanded accordingly.

d. Shade bands if used shall meet the requirements of SAE recommended practice J100.

e. Except for shaded areas, covered above, the luminous transmittance in Zones I through V shall be at least 80% and that in Zone VI shall be at least 70%, as measured per ANS Z26.1, Safety Code for Glazing Materials for Glazing Motor Vehicles Operating on Land Highways.

f. Sun visors are required.

g. The contractor may elect to eliminate corner reference points (ref. paragraph S 7.2) for other safety considerations; e.g., pedestrian safety.

h. Only binocular measurements will be used in determining the obstructed angles in the direct field of view. Binocular or monocular measurements are acceptable for determining target areas visible using indirect systems.

i. The horizontal angular width of obstructions in Zones II and III (ref. paragraph S 9.1(b)) shall not be more than 6° and that of obstructions in Zones IV and V (ref. paragraph S 9.1(c)) shall not be greater than 12°. There shall be no more than four pillars (i.e., two "A" pillars and two "B" pillars excluding vent window pillars) in a 270° arc which is 135° to either side of a line passing through point V_o parallel to the X plane. The steering wheel, windshield wipers and head restraints shall not be considered as obstructions; however, the head restraints shall be designed to provide the minimum obstruction possible consistent with their intended function; e.g., "ring type" or transparent designs.

j. The dimensional criteria for electrical conductors are deleted. The contractor will provide data on the amount of obstruction present.

k. All adjustable indirect visibility devices except the right side mirror, if used, shall be adjustable from the driver's seat. The side mirrors, if used, may be convex; i.e., with a spherical or cylindrical curvature having a single radius of curvature providing 0.5 or greater magnification at the design eye distance. If system design conditions dictate, the contractor may elect to request NHTSA approval for an indirect visibility subsystem using a stepped inside mirror and/or less than 0.5 magnification for the right hand outside mirror.

There shall be a wiper system for the backlight (rear window) designed to clear 75% of the glazing surface within an unobstructed area of Zone VI. The backlight shall be heated for defrosting purposes.

The car shall meet the requirements of FMVSS 107, with requirements within Zones I, II and III of the driver's direct field of view. As a minimum, the windshield defrost/defog subsystem shall meet the requirements of FMVSS 103.

2.2.2 Lighting

As a minimum, the vehicle lighting shall meet the requirements of FMVSS 108 with the proposed or allowed revisions published in 37 FR 22801, and 38 FR 33084.

A three beam headlight system shall be provided having the following forward illumination characteristics:

- Low beam 20,000 candela
- Mid beam 60,000 candela
- High beam 155,000 candela

These beams shall provide the forward illumination patterns shown in Figure VII.

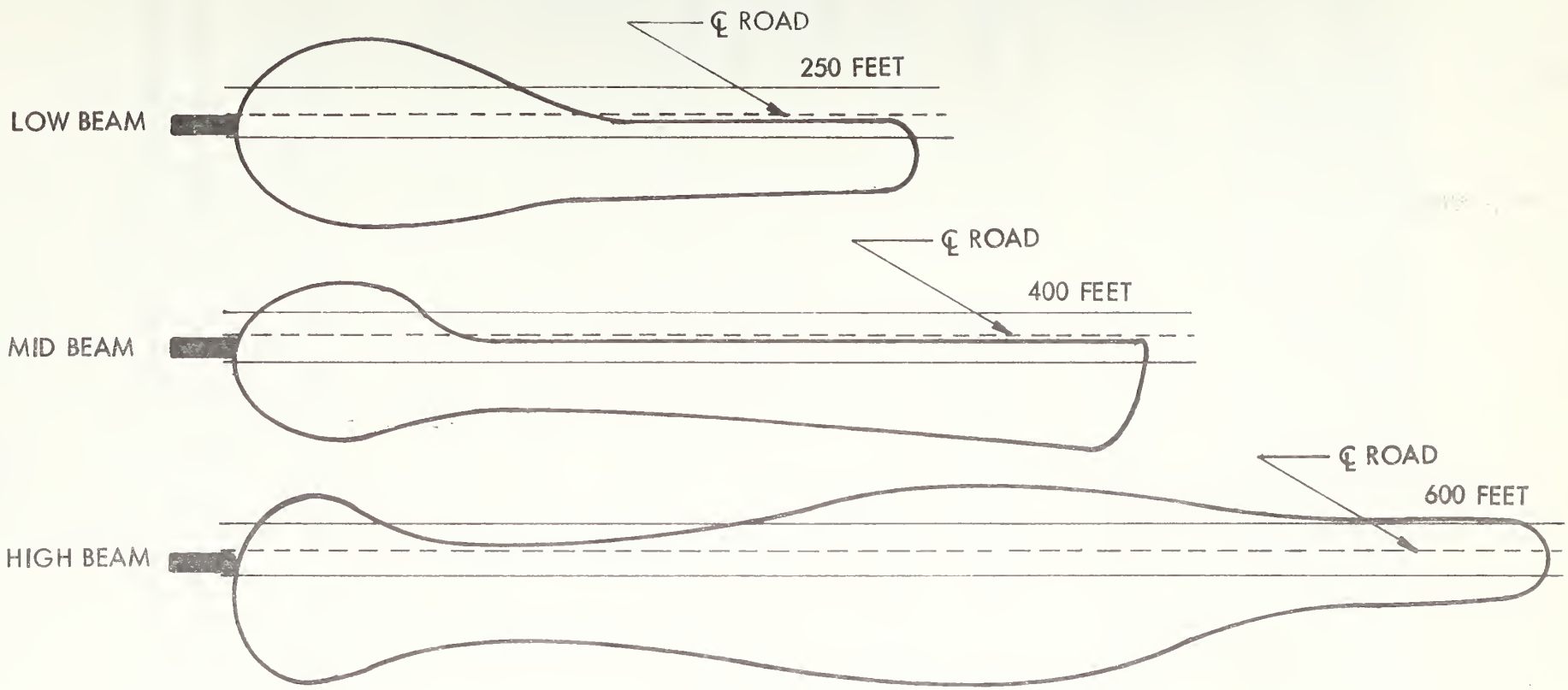


Figure VII. Head Lamp Beam Pattern

The rear lighting system shall be arranged with separate presence, turn and stop signal lamps, additiona turn and stop signal lamps provided for desirable redundancy. A deceleration lamp shall be incorporated to denote vehicle deceleration. The color coding for the designated lamps shall be as follows:

- Stop - red
- Presence - blue or blue-green
- Turn - yellow
- Deceleration - yellow

Front signal lamps shall be provided to indicate turn and presence.

2.3 DRIVER ENVIRONMENT SYSTEMS

2.3.1 Controls and Displays

The requirements for controls and displays shall conform with human factors considerations to provide optimum safety in controlling and monitoring the vehicle in all driving situations. The safety to be provided shall, typically, be in the form of early warning of unsafe vehicle conditions, clear and non-ambiguous instrument displays, and minimum potential for unintentional or inadvertent actuation of controls.

The controls and displays shall represent the advanced state of the art in human factors cirteria for vehicle operation and in the control and display devices and instrumentation.

In addition, the controls and displays are to be compatible with crashworthiness and occupant protection requirements stated in this and other sections of the specifications.

The vehicle instrumentation shall be appropriate to the monitoring needs related to safe functioning of the handling and stability, visibility, driver environment, and other vital vehicle systems.

The speedometer and odometer shall conform to SAE J678d containing speed indication to 85 mph and accumulated distance traveled in increments of 0.1 miles. The speed and distance data may be displayed in digital form.

The foot pedals shall prevent inadvertent simultaneous movement of different foot pedals by the same foot, incorporating non-skid characteristics and be suitable for all foot gear; i.e., including heavy overshoes.

The driver's seat and control adjustment shall be adequate to accommodate individuals ranging in size from a 5th percentile female to a 95th percentile male. Means shall be provided for retaining the driver in such a position that he can operate the steering, service brake and throttle controls under resultant accelerations up to 1 g.

2.3.2 Warning Devices

The vehicle shall have a horn satisfying the requirements of SAE J377.

The vehicle shall have a speed warning system audible to the driver which sounds at an activating speed which is adjustable by the driver to any speed from 25 to 85 mph. At 85 mph, the speed warning device will be automatically activated.

Warning lights and/or audible signals to alert the driver to unsafe mechanical and electrical conditions or failures; e.g., engine overheat, low oil pressure, door open, or excessive brake lining wear, shall be provided. These devices shall supplement the display instrumentation to minimize inattentiveness to any instrumentation readings indicating potentially hazardous status.

There shall be a restraint system conditioning monitoring circuit which provides a visible and an audible warning in the event that the system becomes inoperative or improperly used.

2.3.3 Environment

As a minimum, a heating and ventilation system with temperature and vent controls shall be provided.

There shall be a positive pressure in the passenger compartment under all operating conditions. The carbon monoxide concentration shall not exceed 25 ppm when tested per SAE J989.

The air conditioning system, if provided, shall be sized for full occupant capacity and maintain acceptable interior temperature levels under the average range of climatic conditions prevalent in the U.S.

The interior noise levels shall not exceed the decibel (dBA) levels under the following driving conditions:

- Idle 52
- Steady 30 mph 62
- Steady 50 mph 67

2.3.4 Emergency Equipment

Provisions shall be made for readily accessible storage of road emergency equipment. All such equipment shall be securely mounted to the vehicle and not located in any of the crush zones, and if outside of the passenger compartment, shall be on the non-traffic side of the vehicle. Equipment shall include as a minimum:

1. Fire extinguisher
2. Spare electrical fuses (if used)
3. Stopped vehicle warning devices to include:
   - Three flares
   - Red emergency reflective triangle
4. First aid kit
5. Electric lantern

2.4 CRASH ENERGY MANAGEMENT SYSTEMS

The RSV shall be designed to provide structural and occupant protection performance as specified in this section. Structural performance requirements are specified to (1) utilize both the structure and interior occupant protection systems to the extent currently feasible in mitigating forces on occupants in the vehicle in all specified crash modes; (2) provide

a safe environment for struck vehicles (i.e., low aggressiveness) in collisions with the RSV; (3) provide protection against damage in low speed crashes; and (4) provide a "low hostility" environment in pedestrian and cyclist crashes. Performance requirements for each of these conditions are established in this section as a best estimate of desired vehicle capability considering the current state of the art in crashworthiness design, preliminary evaluation of weight and cost effectiveness practicality, and design achievability. It is anticipated that refinements to this Phase I evaluation will be made in Phase II as RSV design data becomes available, and the vehicle structural and restraint configurations and performance characteristics are more accurately defined.

To cimplify the specification of performance in this section, all accelerations and decelerations are stated as accelerations; also, all impact velocities, whether forward or rearward, and whether pre-crash or imparted, are stated as velocities.

2.4.1 Structural Systems

The structural systems identified in this specification are basically the primary impact areas. This breakout assumes that related structure such as the floor, for example, will be functionally integrated into the overall structure to complete the vehicle. The primary structural systems are:

a. Front structure
b. Side structure
c. Roof structure
d. Rear structure

These structural systems, in addition to serving as primary impact areas, when combined with the floor and other sub-structures, form the passenger compartment. Regardless of the direction of impact, the passenger compartment and its occupants must be protected from excessive intrusion, and acceleration.

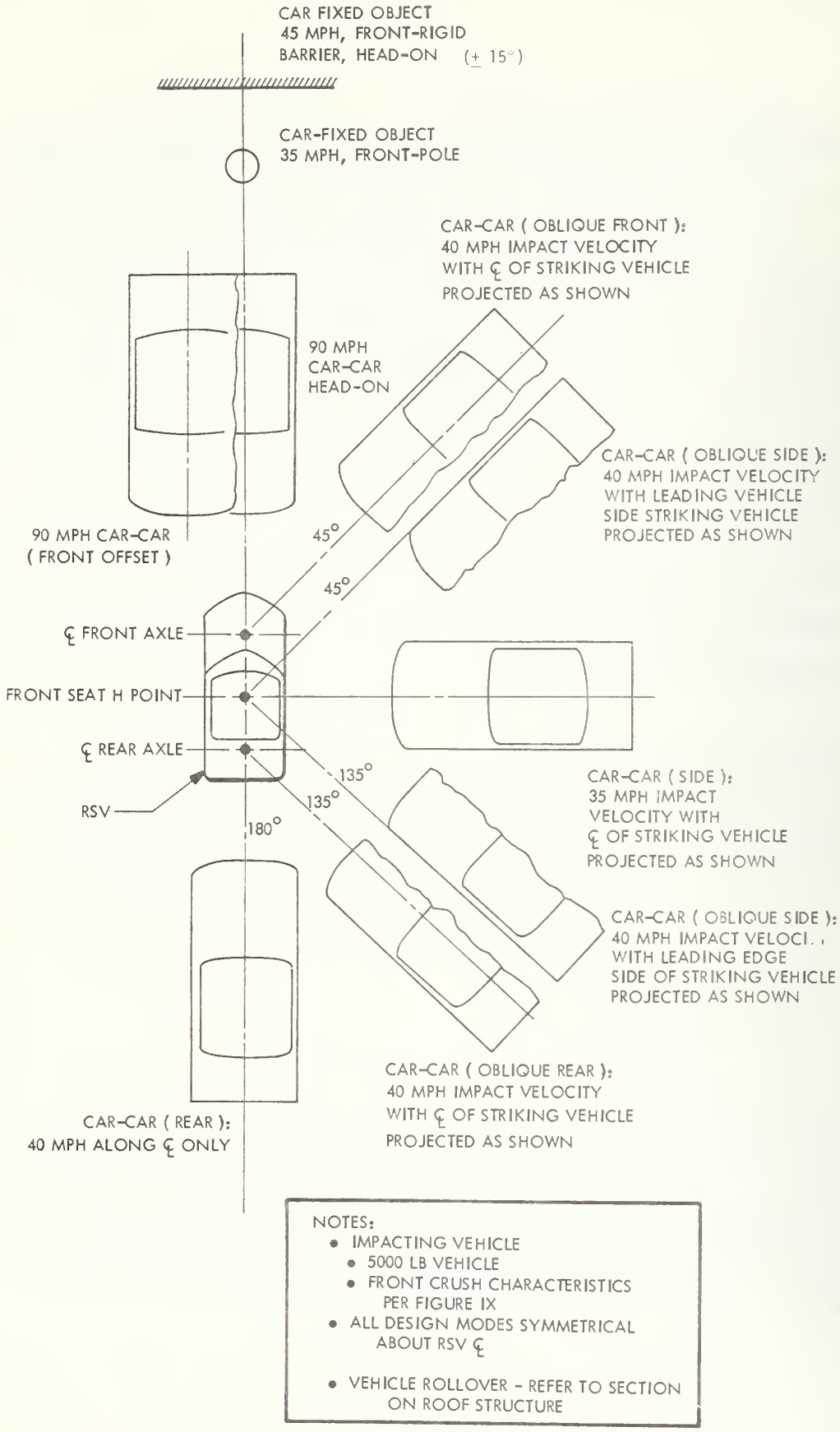


Figure VIII Design Crash Modes

Minimum passenger compartment intrusion consistent with optimized performance and weight is desired. In the absence of technical justification, residual intrusion greater than three inches from the normal inside surface to which the padding or lining is attached will not be permissible. When greater intrusion is allowed, it shall be shown (1) that an increase in intrusion will not significantly increase the probability of entrapment, serious injury or death to the occupants, (2) that the intrusion will be controlled, and (3) that the intrusion can be limited to the approximate values and areas proposed.

The occupant protection requirements given in Section 2.5.2 are applicable for all design crash modes defined in Figure VIII.

2.4.1.1 Front Structure

Figure IX graphically depicts the allowable dynamic crush characteristics for the front structure of the RSV and its opposing vehicle (5000 lb vehicle) for compatibility in the vehicle-vehicle collision modes defined in Figure VIII. Single excursions in the dynamic load (or associated passenger compartment accelerations) of up to five milliseconds duration above the boundary given in Figure IX are permissible.

The lateral crush load of the front structure will be limited to 60 kips to be compatible with the RSV in a side-swipe configuration.

The front structure shall be designed to provide performance in front-to-side crashes in accordance with the paragraph on side structure and in front-to-rear crashes in accordance with the paragraph on rear structure.

Provisions shall be made for a 4 inch damage "free" stroke of the front bumper (and/or front structure) with a maximum acceleration of 5 g's.

The front and rear bumpers shall provide protection against underride/override when loaded to 50% of the rated load from a height of 10 inches to 16-1/2 inches during either maximum acceleration or panic braking.

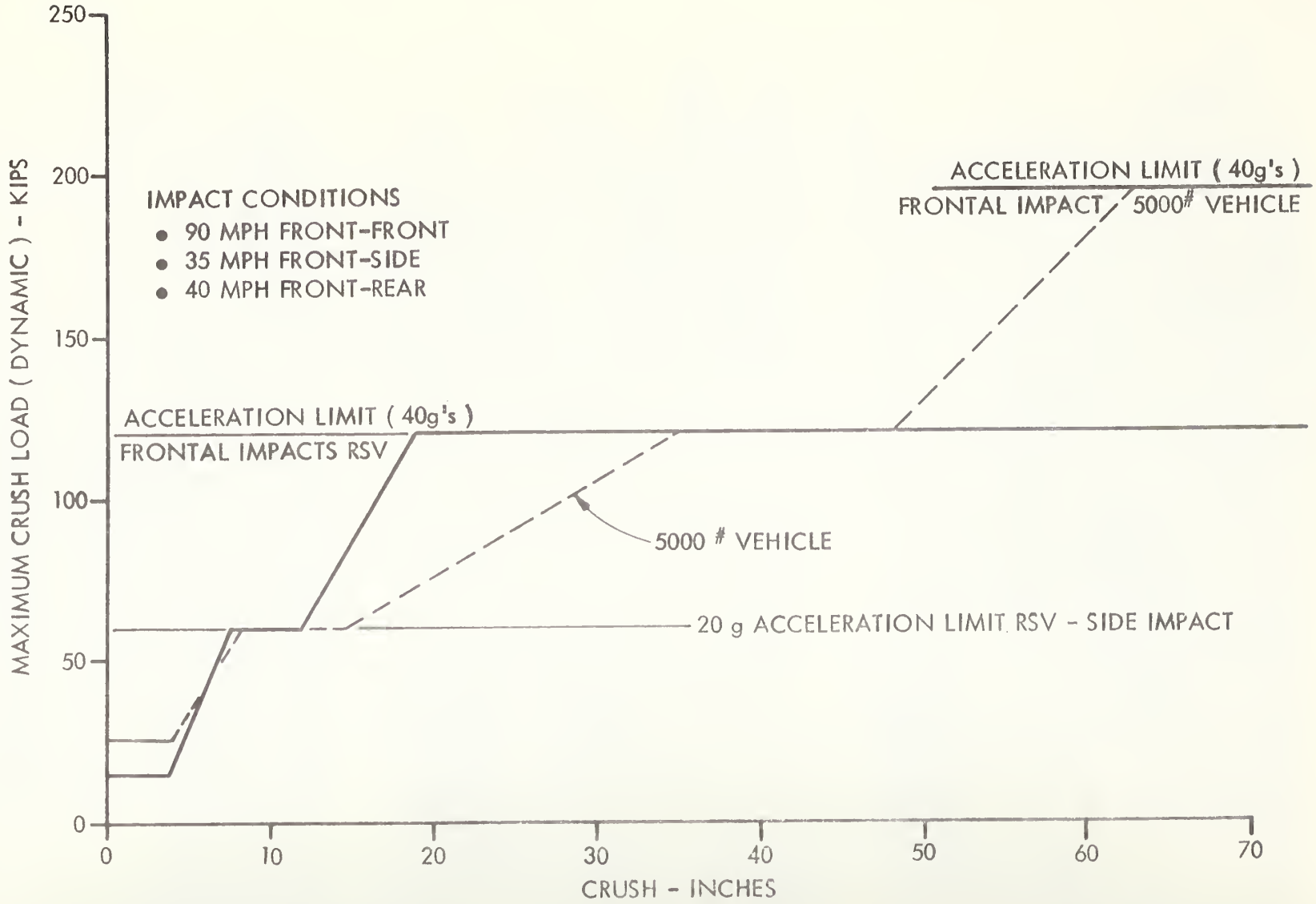


Figure IX . Front End Stiffness Characteristics for Vehicle-Vehicle Compatibility

The profile of the vehicle front end shall be such that no "hard" structures (e.g., hood, grill, and associated back-up structure) can make contact with the impacted vehicle side structure above the belt line during impact. If such contact is unavoidable, the striking surfaces shall be designed to deform away from the side structure without imparting severe damage and resulting passenger compartment intrusion.

2.4.1.2 Side Structure

The side structure/door system shall be designed for side collisions to 59 ft/sec (40 mph) when struck under the conditions shown in Figure VIII by a vehicle weighing 5000 lbs with front structure longitudinal performance specified in Figure IX, and lateral characteristics compatible with the RSV side structure (60 kips maximum crush load).

2.4.1.3 Roof Structure

The roof structure shall be capable of demonstrating satisfactory rollover performance by testing a dolly-mounted vehicle which is rolled from a dolly at a velocity of 30 mph in accordance with the rollover test described in FMVSS 208.

2.4.1.4 Rear Structure

Rear-end crash modes are given in Figure VIII. Compatibility with the front structure specified in the paragraphs on front structure shall be provided.

The bumper shall provide protection against underride/override when loaded to 50% of rated load from a height of 10 inches to 16-1/2 inches during either maximum acceleration or panic braking.

2.4.2 Exterior Protection

To the maximum extent consistent with the requirements of the specifications for crashworthiness for reduction in highway injuries or fatalities, the vehicle shall be designed so as to reduce or eliminate body damage vulnerability in low speed collisions.

As a minimum, both front and rear exterior protection systems shall be capable of sustaining pendulum collision tests of 5 mph as well as barrier collision tests of 5 mph with the vehicle's power plant operating and the power train in neutral position without producing any vehicle body, suspension, or power train damage. The pendulum and barrier collision tests shall be as specified in FMVSS 208.

2.4.3 Fuel System Integrity

No penetration of the fuel tank(s) or energy source and connecting lines or release of fuel from these components shall be permitted under all test conditions described within this specification. Release of fuel from the power plant shall be limited to the minimum amount practicable for the plant design.

2.4.4 Pedestrian/Cyclist Protection

2.4.4.1 Vehicle Design Requirements

Exterior Geometry. In the absence of technical justification to the contrary, the exterior geometry of the vehicle shall conform to the following descriptions:

a. The front surface of the vehicle is defined as that portion of the vehicle skin (excluding the bumper) forward of the leading edge of the windshield. The rear surface of the vehicle is defined as that portion of the vehicle skin (excluding the bumper) rearward of the trailing edge of the backlight. The front and rear surfaces of the vehicle shall have the following geometry.

- The intersection of the front or rear surface and any intersecting horizontal plane shall describe a convex curve with the apex lying on the vehicle centerline.
- The intersection of the front or rear surface and any intersecting vertical plane which is parallel to the longitudinal axis of the vehicle shall describe a convex curve. The extreme forward or rearward point (as appropriate) of the curve shall be located at the lowest extremity of the vehicle front or rear surface (as appropriate).
- The vehicle skin adjacent to each wheel well shall be contoured as required to preclude protrusion of any portion of the wheel/tire beyond an imaginary surface bounded by the rim of the wheel well opening. In the case of the front wheels, this requirement applies only when the wheels are in a zero yaw position.

b. The side surfaces are defined as those portions of the vehicle skin and glazing that are located between the leading edge of the windhsield and the trailing edge of the backlight and lie in a general vertical plane parallel to the longitudinal axis of the vehicle. The side surfaces shall have the following geometry.

- The intersection of a side surface and any intersecting vertical planp which is perpendicular to the longitudinal axis of the vehicle shall describe a convex curve with the extreme outboard point located at the lowest extremity of the vehicle side surface. This requirement does not necessarily include the side glazing.
- The geometry of all side glazing and the design of any adjustable side glazing shall preclude protrusions of any

portion of the side glazing beyond an imaginary surface bounded by the adjacent vehicle skin.

c. All bumper faces shall be vertical and shall have a vertical dimension of at least 8 inches.

d. If wheel covers are used, the wheel covers shall have a convex shape and its surface shall be free of sharp protrusions.

Exterior Finish. The finish applied to the vehicle skin, bumpers and wheel covers shall contain no abrasive or frictional materials except as may be required to enhance the control of pedestrian/cyclist dynamics during and/or after impact.

Exterior Protrusions. Exterior vehicle protrusions, other than those provides expressly for pedestrian safety, shall be eliminated or recessed to the maximum extent feasible. Protrusions other than those provided expressly for pedestrian safety which cannot be eliminated or recessed shall be designed to crush or break away when contacted from any direction if (a) a pressure of 80 psi is exceeded, or (b) a pressure of 50 psi is maintained for a period of more than 5 milliseconds.

All exposed bumper surfaces shall be covered with energy absorbing material. The amount and characteristics of the material used shall be commensurate with minimizing pedestrian injuries.

Visibility. No requirements exist beyond those specified in paragraph 2.2.1 of this specification.

Audio/Visual Signaling. A driver-operated audible signaling device shall be provided as specified in paragraph 2.3.2 of this specification.

No visual signaling devices are required other than those specified in paragraph 2.2.2 of this specification.

2.4.4.2 Vehicle Design Goals

Provisions should be made to control the trajectory of pedestrians or cyclists who are impacted by the front of the vehicle at velocities above 10 mph. In this situation, the pedestrian/cyclist should be (1) propelled onto the vehicle hood if initial contact is between the inner edges of the front tires (in zero yaw position), and (2) propelled out of the vehicle path if initial contact is outboard of the inner edge of either front tire (in zero yaw position).

In conjunction with the above paragraphs, the vehicle hood design should incorporate injury attenuating energy absorption where feasible and shall be free of sharp protruding edges and narrow hard surfaces that can inflict piercing or cutting injuries to the victim while in contact with the vehicle.

2.5 OCCUPANT COMPARTMENT SYSTEMS

2.5.1 Seating Systems

The front and rear seating systems shall be designed to provide reasonable occupant protection under all crash modes described in Figure VIII. The seating system shall be functionally integrated with occupant restraint system performance.

During rear vehicle impact, the seats shall provide adequate head, back and whole body restraint to retain the occupant, prevent hyperextension of the neck, and assure that tolerable occupant accelerations and local loadings are not exceeded. Rearward translation and deflection of the front seats shall be limited to the extent necessary to prevent imparting injury-producing loads on rear seat occupants and to assure retention of front seat occupants.

In frontal vehicle impacts, the seat systems shall not impose injury-producing forward loads on the occupants during or after deceleration of his forward motion. The seat system shall provide adequate impact

attenuation to prevent exceeding human tolerance levels on occupant loading resulting from any rebound phase of the occupant restraint system.

In angular and lateral vehicle impacts, the seat system shall be integrated with door padding, consoles and other interior components to limit loading of the occupants to tolerable levels. The seat systems shall also limit vertical loading on the occupants to tolerable levels during all operating and crash conditions under which they are contacted by the occupant.

The seat and head restraints shall satisfy all requirements of FMVSS 201 and 202 as a minimum. For unique head restraint designs which make compliance with the specified test conditions of the FMVSS 202 technically inappropriate, the system must, under the conditions of maximum forward vehicle acceleration resulting from prescribed vehicle design conditions of Section 2.4, restrict head rotation relative to upper torso to angles not exceeding 60° and head impact conditions to values not exceeding head injury criteria value of 1000 as defined in FMVSS 208. In general, the seating system shall satisfy the requirements specified in Table III.

Table III

SPECIFICATION FOR RSV SEATING SYSTEM

Specification	Requirement
Rear impact speed*	40 mph
Head acceleration (P-A)	HIC 1000
Chest force (P-A)	60 g/3 msec
Head rotation	60°

*car-to-car

2.5.2 Occupant Restraint Systems

Load distributions on various portions of the body are known to be critical parameters influencing serious occupant injury and survival. Human tolerance to localized loading (in terms of load per unit area) is not currently adequately defined. It is therefore a goal in this program to utilize practical means to minimize local load applications to the body.

To the extent practical, all controls and interior protrusions shall be recessed or shielded making them noncontactable by an occupant whether restrained or not. Where this is not practical, all contactable interior protrusions shall be frangible, crushable or have breakaway properties. All other interior surfaces shall minimize local forces on the occupants. A design goal shall be that no more than 50 psi contact pressure shall be developed for more than five milliseconds between any interior surface or prortrusion and a colliding occupant for all directions and magnitudes of crash modes specified in this document. Short-time peaks in pressure greater than 50 psi, but not to exceed 80 psi, will be allowed for periods not to exceed five milliseconds.

Vehicle interior surfaces which are contactable by the face of an occupant during crash shall be designed to provide no greater than a 200 pound resistance to penetration of a 6-1/2 inch diameter rigid head form weighing 11.5 pounds during dynamic impact of the crash condition until a one inch penetration has been exceeded. During the initial one inch penetration of the head form, at least 50 inch pounds of energy shall be absorbed. Transparent glazing shall not be subject to these requirements at this time.

For all directions and magnitudes of crash tests specified herein, the additional injury criteria (a) through (e) shall not be exceeded.

(a) All portions of the test device shall be retained within the vehicle passenger compartment throughout the test.

(b) The resultant acceleration at the center of gravity of the head shall not exceed a head injury criteria level of 1000 calculated by the method described in FMVSS 208.

(c) The resultant acceleration at the center of gravity of the upper thorax shall not exceed 60 g, except for intervals whose cumulative duration is not more than three milliseconds. Additional restrictions on the acceleration magnitude along the orthogonal axes shall be: A-P acceleration shall not exceed 60 g for periods exceeding three milliseconds duration; S-I acceleration shall not exceed 20 g for periods exceeding three milliseconds; laterla acceleration shall not exceed 30 g for periods exceeding three milliseconds.

(d) The force transmitted axially through each upper leg shall not exceed 1700 pounds.

(e) Rearward angular displacement of the head reference line shall be limited to 60° from the torso reference line under the specified vehicle rear impact conditions in Figure VIII.

An onset rate of 1500 g per second or less shall be a design goal for the occupant chest when the following conditions exist:

1. A change in g level up to 20 g occurs, and
2. When upper g level is sustained for a period up to 10 milliseconds.

Occupant protection systems shall be selected on the basis of the relative cost benefit merits of alternative systems. For an occupant protection system which includes a functional mechanism for crashes above a specific speed, requirements of (a) through (d) above shall be satisfied at crash speeds 5 mph higher than the predetermined speed without benefit of the mechanism of device as well as at impact speeds at 5 mph lower than the predetermined speed.

2.5.3 Flammability

The energy, electrical and exhaust systems shall be designed to assure containment of fuel or corrosive liquids in a variety of crash modes or vehicle attitudes, as well as the exclusion of volatile materials coming in contact with potential ignition sources. Interaction of the structure when deformed or when scraped on road surface must not affect the fuel or energy system by causing excessive spillage or ignition of flammable liquids or gases by sparks of a scraping structure or electrical discharges.

Interior materials that will not support combustion, will not melt, and will not emit tocix fumes when exposed to flame or high temperatures shall be used to the extent practical. The flammability requirements of FMVSS 302 shall be met.

A small fire extinguisher (not to exceed 2.5 pounds in weight) shall be provided in the occupant compartment of the vehicle. The extinguishing agent should be rated for small Class A, Class B and Class C fires, and when used under fire conditions, should not have severe or prolonged harmful effect on humans. The extinguisher shall be readily available for the driver and front seat occupant, easily recharged, easily inspected and inexpensive.

2.5.4 Interior Design

The interior occupant compartment design shall satisfy FMVSS 201 as a minimum. The restrained occupant shall be provided with adequate stroking distance during the frontal crash modes defined in Figure VIII to minimize contact with the vehicle interior. For side impacts, as specified in Figure VIII, the occupant/interior impact force shall not exceed the human tolerance limits specified in paragraph 2.5.2. The steering control system shall satisfy the impact requirements in FMVSS 203 and 204.

2.5.5 Emergency Egress

Consideration shall be given to providing the RSV for provisions for occupant escape or rescue from the passenger compartment in any attitude it may have as a result of collision, rollover, or submersion. Geometry and space availability to accommodate the large variations in age and size of occupants and the operational features of any latch and release mechanism to be used under adverse conditions of injury, panic, darkness, and unusual vehicle orientations must be considered.

3.0 VEHICLE SYSTEMS REQUIREMENTS

The major portion of the preceding RSV specifications are directed toward those systems whose performance is vital to safety in the projected usage and accident environment. The remaining vehicle systems, directly and indirectly safety related, shall be equivalent to the state of the art projected for production vehicles in 1985. The vehicle systems shall be designed to withstand normal service conditions and/or loads encountered throughout their normal life without failure. No unusual maintenance or servicing actions shall be required and routine replacement items (e.g., tires, batteries) shall be readily available to the consumer.

It is anticipated that the life of the 1985 production vehicle will be extended beyond the present 10 year life expectancy to possibly 15 years in order to conserve the energy and material resources required to produce and operate automobiles. The life factor shall be a design consideration.

3.1 POWER PLANT, FUEL, COOLING AND EXHAUST SYSTEMS

The power plant, fuel and exhaust systems shall meet all requirements for control of air pollution for new motor vehicles and new motor vehicle power plants as specified in the Federal Register, Vol. 37, No. 221 and any subsequent updating thereto relating to the mid-80's. The standards used for RSV exhaust emissions shall be the same as for the production

vehicle requirements for the 1985 period of vehicle manufacture. Tests shall be conducted to obtain emission data on one vehicle; no emission durability tests will be conducted.

The power plant cooling systems shall be designed to perform in accordance with normal automotive standards. Engine coolants shall comply with SAE J814 and system materials shall provide for satisfactory service life.

The exhaust system shall be designed in accordance with standard automotive practice and shall be fabricated from materials which provide acceptable service life.

3.2 TIRE AND WHEEL SYSTEMS

The tires and wheels selected for the RSV shall meet the requirements of FMVSS 109 and 110.

If runflat devices are used in the vehicle tires, the vehicle with 100% rated load and single tire deflation on either the front or rear wheel on the driver's side shall have:

- A minimum of 3-1/2 inches of ground clearance, and
- A range capability of 100 miles of travel at 50 mph.

3.3 ELECTRICAL SYSTEM

The electrical system shall be designed to accommodate all normal operating loads (ignition, lighting, brakes, instrumentation warning systems, etc.) and normally utilized accessories. Wiring harnesses, fuses, alternator/generator and storage battery shall be sized with sufficient margin to provide economical and low maintenance operation over the life of the vehicle.

3.4 INTERIOR COMFORT

Provisions shall be made for driver and passenger comfort in accordance with conventional automotive practice. These shall include fresh air ventilation, courtesy lighting, radio and clock. The passenger compartment shall be thermally insulated to minimize interior temperature fluctuations arising from both vehicle and exterior heat sources; acoustical insulation shall be provided to reduce interior noise arising from both vehicle and exterior noises. Interior storage shall be provided in the form of glove compartments, map pockets, etc.

3.5 MAINTENANCE

All vehicle systems shall be designed to withstand service conditions or loads throughout the life of a normal production vehicle. In all systems, ease and economy of maintenance as well as safety of maintenance operations shall be considered.

Provisions shall be provided for plug-in with any standardized automotive diagnostic system(s) that may be implemented in the mid-80's.

4.0 PRODUCIBILITY

In addition to meeting the safety and functional performance requirements set forth in the preceding sections of this specification, the design and production of the RSV shall reflect the resources, technology, and markets projected for the industry in the mid-80's. The producibility requirements associated with these considerations follow; an annual production rate of 500,000 units is projected for the vehicle class represented by the RSV.

4.1 MATERIALS AND APPLICATIONS

The materials and fabrication and assembly processes required by the production designs of the vehicle shall be in accordance with the technology and design trends projected into the mid-80's. Significant

departures from currently projected technology or trends in any of these areas shall be justified in terms of automotive industry acceptance criteria (lead times, capital investments, costs, etc.), the impact on energy and material resources, economic factors, and other related producibility considerations.

4.2 COMPONENTS AND SUBSYSTEMS

The functional elements of the vehicle (power system, brakes, suspension, lighting, etc.) shall represent production designs commensurate with the advances projected for these elements in the mid-80's.

4.3 PROTOTYPE RSV

A prototype RSV is defined as the experimental vehicle(s) manufactured, in advance of its intended production time frame, for test and demonstration purposes. Accordingly, proprietary data restrictions, development and/or manufacturing costs, or limited material or product availability may preclude the prototype RSV designs and manufacture from complying with production design specifications. For these areas where such constraints exist, the specific design, material, or product which would provide compliance shall be identified. An alternative design, material, or product shall be proposed as a replacement for use in the prototype RSV, and submitted for DOT approval. The selection of the alternative(s) shall be supported by appropriate studies. The estimated deviation(s) from performance specifications resulting from the use of the proposed alternative(s) shall be defined.

5.0 APPLICABLE DOCUMENTS

The following documents are incorporated herein; in the event of any conflicting requirements, the RSV specification takes precedence.

5.1 FMVSS and applicable advanced notices
5.2 FMVSS program plan (appropriate issue)
5.3 SAE standards and recommended practices
5.4 Other date effective technical reports on performance criteria.

5.2 SUPPORTING RATIONALE

This section presents the basis on which the performance specifications for the RSV, presented in Section 5.1, were developed. The numbering and titles of the paragraphs and sub-paragraphs in Sections 5.1 and 5.2 are the same so that the rationale and/or justification used in establishing any requirement in Section 5.1 can be readily found under its corresponding number and title in Section 5.2.

In developing the RSV performance specifications, the DOT Technical Specifications, U.S. Intermediate ESV, dated February 16, 1973, were utilized not only as a guideline for scope and comprehensiveness, but also as a potential source of technical data founded on a considerable amount of prior work conducted by and for the NHTSA. In some instances, the specifications contained in the guideline document were found to be applicable to the RSV; in other instances, the findings of the RSV program definition study required differing specifications. Therefore, it was deemed appropriate in Section 5.2 to comment on the similiarities and differences in the guideline (IESV) and RSV performance specifications.

1.0 GENERAL DESIGN REQUIREMENTS

1.1 OBJECTIVES

The objectives of the RSV program were restated to reflect the increasing national concern with energy conservation as a long-term problem. The implication for the RSV of this concern is that the safety performance objectives are to be achieved with a significantly more efficient use of fuel and material resources.

1.2 VEHICLE DESCRIPTION

The specifications for this area are presented in a form intended to preserve a performance rather than design oriented set of requirements and to conform, where practical, with automotive industry definitions, standards,

or practices. With this basic intent established, the rationale for specifying the component elements of the overall vehicle description follows.

Usage projections indicated that a 4-passenger vehicle would satisfy all the average occupancy requirements for all trip purposes. The larger classes of cars extant in the mid-80's would fulfill the needs for over-average occupancy. For most trip purposes, the sedan body style is considered to be a more appropriate car configuration, and is anticipated to retain its high market share relative to a station wagon body. Within the sedan body style, either a 2- or 4-door arrangement is acceptable; although subsequent design analysis may indicate some safety advantages may be inherent in one of the arrangements.

At this point in formulating the basic vehicle specifications, consideration was given to the characteristic which would specify the RSV size classification. The generally accepted industry standard, established by Automotive News for reporting domestic car production, consists of three major classifications: small, intermediate, and large; the small classification is further sub-divided into mini, subcompact, compact, and luxury small classes. There are no precise definitions for any class; Automotive News generally associates wheelbase, overall length, and manufacturer's intent with each class. Dimensionally, the range of wheelbase, overall length, and weight for 1975 U.S. production models in the small car classes are as follows:

Class	Wheelbase, in.	OA Length, in.	Weight, lbs.
Mini	None in production		
Subcompact	94.5-97 (96.2)*	169-178.8 (174.2)	2495-2766 (2608)
Compact	103-109.9 (108.9)	187-201.8 (195.8)	2936-3531 (3262)
Luxury Small	96.2-109.9 (101.6)	175-199.9 (185.4)	2752-3425 (3054)

*Numbers in ( ) indicate average value.

For comparison purposes, the ESV's made by overseas manufacturers in the 2500 to 3000 pound curb weight class had a wheelbase range of 90.5" to 103" (97") and an overall length range of 166" to 177" (172"). Therefore, with a stipulated maximum curb weight of 3000 pounds, the appropriate size classification for the RSV is judged to be the subcompact.

The guideline DOT specifications for the U.S. Intermediate ESV defined maximum values for a set of exterior dimensions. While these values are liberal when compared to the cited subcompact cars and ESV's, they are design oriented. Therefore, the exterior dimensions in this specification are defined as a function of the size classification with the added constraint of maximum curb weight.

In specifying the requirements for interior dimensions, the guideline specifications defined dimensional goals for the effective head, leg, and shoulder room. Goals are considered to be ambiguous, and are avoided where possible. For the RSV specification, the interior dimensions are also defined functionally. If a manufacturer provides an effective leg room (L51) that requires the 50th percentile male occupants to sit in a skewed position, then that dimension is not compatible with the specified interior.

Also, the RSV specification increases the number of dimensions to be considered in accordance with the MVMA definitions for both the interior and exterior car and body dimensions. This requirement will provide a more comprehensive and uniform description of the manufacturer's car for comparative evaluations.

2.0 SAFETY PERFORMANCE REQUIREMENTS

The introductory paragraphs under this heading have been restated to require the consideration of the performance of individual systems in terms of their influence on the performance of the total vehicle system and to reflect the projected needs of the mid-80 environment.

2.1 VEHICLE HANDLING AND STABILITY SYSTEMS

The guideline specifications required the vehicle under test to be loaded to 60% capacity. The loading condition has been revised to provide a more specific definition of usage loads and their distribution and thus require the test conductor to arrange test instrumentation and any required ballast in a configuration representative of the design conditions. The specific definition is considered necessary because (a) the vehicle's dynamic performance is more sensitive to the fore/aft load distribution than to the load itself, and (b) clockwise and counterclockwise performance is usually not the same because of asymmetries in the vehicle and its load; by maintaining symmetry of the load around the vehicle's longitudinal axis, performance measurements will reflect only the effects of inherent vehicle asymmetries.

2.1.1 Braking Performance

The braking system is vital to the accident avoidance performance of a motor vehicle. Improved braking system performance should either avoid a potential accident by decelerating the vehicle to a stop within available time and distance, or in case the accident cannot be avoided, reduce the severity of injuries and damage by decelerating the vehicle to a lower impact velocity. Unfortunately, available accident studies do not provide any quantitative data on the degree to which specific improvements in braking performance would decrease either the frequencies or severities of accidents. However, there are studies on driver behavior and accident causal factors that provide some insight into the relative importance of the systems related to handling and stability performance; the findings of these studies provided some guidance in establishing system requirements.

J.C. Fell and V.J. Esposito reported on various accident avoidance [1] maneuvers attempted by younger and older drivers. The results, shown in the table that follows, emphasize the central importance of the braking system by showing that drivers normally tend to use braking alone or combined

braking and steering as primary accident avoidance maneuvers. The braking system participates in 40% of the attempted 52% of the accident avoidance maneuvers undertaken by young drivers (age 15 to 24); for older drivers (age 25 to 70+), out of 47% attempted accident avoidance maneuvers, 38% involved braking.

TYPE OF ACCIDENT AVOIDANCE MANEUVERS BY AGE GROUP

Avoidance Maneuvers	Young (15-24)	Older (25 to 70+)
None	478 (48%)	825 (53%)
Braking	240 (24%)	399 (26%
Steering	114 (12%)	121 (8%)
Braking and Steering	157 (16%)	190 (12%)
Accelerating	5	10
Accelerating and Steering	2	4
Total	996 (100%)	1549 (100%)

R. Limpert and F.E. Gamero reported similar findings in their analysis of the accident avoidance potential of motor vehicles. [2]

In keeping with these findings, the braking system performance of the RSV was given priority over other handling and stability systems in the formulation of the performance specifications. The rationale for individual braking performance requirements is presented in detail in the paragraphs that follow. The rationale is based on results of the program definition study, analysis of accident causal factors, vehicle performance capabilities, and driver and environmental constraints on safe vehicle performance.

Service Brakes

The performance of service brakes is specified for three types of maneuvers:

1. Straight line braking
2. Braking in a turn
3. Braking on split coefficient surface

These maneuvers represent the three main variations in vertical wheel loads and available tire-road adhesion levels. Straight line stopping takes into consideration the fore/aft load transfer; braking in a turn, the combined fore/aft and lateral load transfer; and braking on a split coefficient surface, the lateral instability introduced by a differential coefficient of friction on the left- and right-hand sides of the vehicle. These three performance maneuvers form the basis for the basic brake system design requirements. The descriptions of the individual parameters in the performance specifications for the service brakes follow.

Load Conditions. Performance is specified for two load conditions: 100% rated load represents the upper limit load condition, and the lightly loaded condition represents about the average load the vehicle will experience on the road. Two load conditions are selected because fore/aft loads and load distribution can be substantially altered under various load conditions, and in turn, influence the stopping distance. The same two load conditions are specified for both braking in a turn and braking on a split coefficient surface maneuvers.

Lane Width. The AASHO Manual on the design of highways and arterial [3] streets requires that the traffic lanes on these roads be 12 feet wide. The width of the traffic lane is governed by the largest vehicle in the traffic, namely, the semi-trailer and full-trailer combination, designated "WB-60", with a wheelbase of 60 feet and an overall width of 8-1/2 feet. In the 1985 environment, even with the projected larger proportion of smaller vehicles on the road, the standard lane width will probably still be governed by "WB-60" and will remain 12 feet as it is today. Hence, the lane width is

specified at 12 feet. It is recognized that narrower roads will be extant in the mid-80's. Since speed is related to lane width, it is assumed that the average driver will drive at correspondingly lower speeds on the narrower roads, and therefore, equivalent braking performance will be had on these roads.

Steady State Speeds. The steady state speed preceding the start of straight line braking is specified at 60 mph. Since the 1973-74 energy crisis, the maximum speed limit on the nation's highways was reduced from an average 65 mph to 55 mph and this limit is anticipated to continue into the future. Even if the maximum speed limits are eventually raised to their former levels, the specified speeds will encompass most high speed needs. The National Safety Council figures for approximate speeds preceding [4] accidents in North Carolina in 1973 are shown in the table that follows. The speed range up to 60 mph covers 93.5% of all accidents, 98.9% of urban accidents, and 88.3% of rural accidents.

APPROXIMATE SPEED PRECEDING ACCIDENTS, 1973

	All Accidents, %		
Speed	Total	Urban	Rural
0 - 9	22.7	30.1	15.6
10 - 19	15.7	19.2	12.3
20-29	14.9	20.5	9.5
30-39	17.2	21.2	13.4
40-49	12.4	5.8	18.7
50-59	10.6	2.1	18.8
60+	6.5	1.1	11.7

Based on these considerations, the specified steady state speed of 60 mph for straight line braking performance is deemed to be appropriate to the maximum speed limits imposed on the nation's highways.

Additional constraints of simultaneous braking and turning or braking on a split coefficient surface reduce the total braking capability of the vehicle and therefore, an initial speed of 40 mph is specified for these maneuvers.

In simultaneous braking and turning (steering), tire limitations under lateral loading (up to 0.3 g lateral acceleration) reduce the total braking capability and the specified speed of 40 mph at the start of this maneuver is commensurate with this limit. The specification for braking on a split coefficient surface is based on that surface being a continuous one rather than a "patchy" one. In encountering such a surface, a prudent driver would normally reduce his speed and it was on this assumption that a 40 mph steady state speed prior to braking was specified.

Straight Line Stopping Distances. A number of guidelines for use in characterization and specification development were prepared as part of the program definition study. These guidelines were based on the findings of accident causal factor analyses. One of the findings was that the basic design and performance of the braking systems in current production vehicles are adequate to cope with the current and projected driving environments, and hence, the resulting guideline is to first provide improved brake system integrity and then, increased performance capability.

In keeping with this rationale, the specified stopping distance and deceleration performance are at levels which are above the average of current production vehicles, but definitely within the capabilities of the mid-80 vehicles when advances in braking technology are considered. The straight line braking performance from 60 mph of recent production vehicles is shown in the following table. The corresponding requirement for the RSV is 160 feet (24.2 ft/sec^2) or 0.75 g.

STRAIGHT LINE STOPPING OF PRODUCTION VEHICLES

Year and Models	Braking Performance	
1973 production All Models	146 (0.82 g) to 233 feet (0.52 g)	[5]
1974 Production All Models	160 (0.75 g) to 258 feet (0.48 g)	[6]
'72-'74 Small and Sports Vehicles	0.93 to 0.6 g	[7]

Further examination of the data in References 6 and 7 indicates that most of the small vehicles in the RSV weight class (3000 lbs and below) with either 4-wheel disc brakes or a disc and drum brake combination fall in a stopping distance range of 146 to 180 feet. Therefore, the specified straight line braking performance of 160 feet (0.75 g) for RSV size vehicles in the 1985 time frame is a reasonable value and will ensure adequate safety performance in the projected traffic environment.

Braking in a Turn and on Split Coefficient Surfaces. The performance specification for braking in a turn is set at a reduced deceleration level of 21.5 ft/sec^2. This level was established by considering a 0.3 g lateral acceleration in turning as the limit of linearity of tire side force properties. For braking on a split coefficient surface, the level specified is 12.88 ft/sec^2 which represents an average deceleration rate for the 25 and 80 skid numbers of the split coefficient surface.

Skid Numbers. The skid number of 80, specified for straight line braking and braking in a turn performance, is representative of a dry concrete surface while the skid numbers of 25 and 80 for a split coefficient surface are representative of an ice or oily patch on one side and dry concrete on the other side. The inclusion of split coefficient braking performance is based on studies by Limpert and by Manger, which criticized specifying [8,9] service brake system performance on straight line braking performance on homogeneous surfaces only.

Pedal Force. Pedal force requirements included in the guideline specifications are taken from extensive studies (e.g., R.G. Mortimer, L. Segel, H. Dugoff, et al, from Highway Safety Research Institute) of pedal force requirements and capabilities of drivers of various sizes from both sexes. The same source data was used in developing the pedal force requirement envelopes depicted in the RSV specification Figure I. For the service brakes in normal operation, 85 pounds of pedal effort was specified to achieve a deceleration level of 0.75 g's. The slope in line 2, defining the upper bound for pedal force for the service brakes, is determined by a minimum gain of 0.012 g/lb which the referenced study found as providing good performance at the high and low deceleration levels. The service brake pedal force of 85 pounds at 0.75 g's is within the physical capabilities of the driver population. [10]

The lower bound for the brake effort for all braking conditions is defined by line 1. This line is based on a maximum gain of 0.021 g/lb which was proved to be the upper limit of gain for good performance. The cutoff of 20 pounds for line 2 pedal force (service brakes) and for line 3 (partial service brake failure) will ensure that under non-panic and/or normal braking below approximately 0.4 g's, the driver-vehicle combination will be provided with comfortable and good modulation with enough brake pedal feel.

For emergency brake performance, 150 pounds of pedal force was specified to achieve a deceleration level of 0.56 g's in the event of a partial (single) system failure and 0.6 g's for a booster failure. The upper pedal force limit, line 4, for the partial system failure is therefore established by the 150 pound value at 0.56 g's and the 20 pound cutoff. Similarly, line 3 limiting the pedal force under booster failure is established by the 150 pound value at 0.6 g's and a cutoff of 30 pounds.

Some uncertainty exists in the ability of all members of the driver population to achieve 150 pounds of pedal force under emergency conditions.

The cited source reference is inconclusive on this point, indicating that the effect of motivation produced by stressful driving situations on foot force is, as yet, unknown. A review of pedal force levels for emergency [11] braking established by other countries indicates that the specified 150 pounds force is at the lower end of their requirements.

In addition to pedal force, consideration was given to specifying a value(s) for pedal travel. A side effect of split hydraulic brake circuits is the free pedal travel associated with single circuit failures. Ingram and Openheimer report that this pedal travel can be as much as three [12] inches for conventional hydrostatic tandem master cylinders. If the circuit failure occurs during a brake application, then there will be an accompanying delay period during which the extra pedal travel must be executed and brake pressure developed to activate the brakes. The driver's reaction to this unexpected and unusual occurrence can result in confusion and the potential of a wrong accident avoidance maneuver.

Germany and Sweden have addressed this specification in their safety [11, standards. 12]

Pedal travel is a function of the foundation brake system design and therefore quantification of pedal travel requirements require analyses of representative brake systems in order to develop a valid set of requirements. Such analyses were judged to be better conducted as a separate study or as part of a succeeding phase of the RSV program.

It should be noted that the absence of pedal travel requirements have no impact on the brake performance specifications presented in Section 5.1.

Braking Performance Evaluation. The Highway Safety Research Insti- [13] tute has developed a procedure for evaluating the braking performance of a vehicle. This procedure determines the braking efficiency by comparing the actual stopping distances achieved by a vehicle with the ideal stopping distances theoretically available if the vehicle brake systems were capable

of modulating brakes so that the tires produced peak braking forces throughout the stop. The procedure also includes a means of comparing tire peak capability on a given surface to that produced by a standard tire.

Table I in the specifications includes five categories of braking performance. Three of them, normal, wet pavement, and minimum load, are applicable for service brakes. The other two, single system failure and booster failure, are applicable to emergency brakes and are discussed later.

The performance values for normal, wet pavement, and minimum load are retained at the same level as specified in the guideline specifications. These values represent a fairly high level of performance and any increase in that level will introduce complexities in the system and add to its cost and weight. The added complexity may offset any gains in safety by improved performance, while the added weight and cost may reduce marketability and benefit/cost ratios.

The braking performance of the Toyota ESV, shown in Table 5-1, [14] provides an indication of achievable performance levels for the RSV. The Toyota braking system is comprised of all 4-wheel disc brakes, hydroboost and antiskid control and is incorporated in a vehicle with a curb weight of 2838 lbs.

Antilock Brake System. Antilock or antiskid brake systems are not directly mentioned or specified in the RSV specifications in keeping with the overall objective to keep RSV specifications performance rather than design oriented. A number of auto manufacturers have offered antilock systems as optional equipment on low volume production, high priced vehicles. Those offered so far usually add on control units to the foundation brake system, which results in a complicated and expensive total package. The situation is anticipated to improve in the coming decade providing an integrated antilock brake system which will be less expensive, more reliable and more compact. These systems will add to the overall safety, particularly on wet surfaces and under limit tire-pavement adhesion conditions.

Table 5-1. Toyota ESV Braking Performance

Braking Conditions	Stopping Distance* (Feet)	Braking Efficiency (Percent)
Normal Braking Dry Concrete, SN=80 Load=112%	131.5	112.8
Normal Braking Wet Concrete, SN=59.6 Load=112%	144.1	141.5
Normal Braking Polished Concrete, Wet SN=50.2, Load=112%	191.6	144.6
Normal Braking Slippery Wet Testing Track SN=33.9, Load=112%	235.8	137.6
Partial Failure Primary System Failed Dry Concrete, SN=80	163.8	90.6
Partial Failure Secondary System Failed Dry Concrete, SN=80	190.0	78.1
Partial Failure Servo Failed Dry Concrete, SN=80	144.9	102.4

*From a 60 mph steady state speed.

H. Manger analyzed the performance of several versions of antilock systems for a passenger car. Table 5-2 compares the performance of these systems for stability, steerability, and braking capability. Approximate additional cost of these systems is listed in the last column. As is seen, progressing from System 1, representing no antilock, the performance is improved at each stage but with corresponding increases in cost. For the RSV, the manufacturer will have to make the decision as to the level of antilock performance to be provided. [9]

AMF analyzed a number of combinations of brake proportioning systems and antilock systems. The system configurations studied are shown in Table 5-3 and Table 5-4 presents an overall evaluation of the six systems. (Note: These systems do not correspond to those in Table 5-2.) [15]

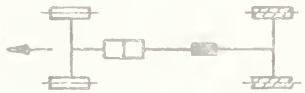
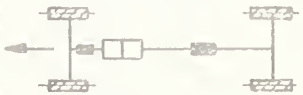
In Table 5-4, overall performance includes the performance categories of straight line braking, braking in a turn, and the influence of vehicle load, and dry and wet surfaces.

Systems 1, 2 and 3 can be readily analysed for weight, cost and complexity because they are production systems. Systems 4, 5 and 6 are nonproduction systems and no data is available for quantitative evaluation. Therefore, only two scales, higher and lower, were used to evaluate the combined category of weight, cost, and complexity.

Both analyses cited point to a definite performance improvement with the advanced systems. Their selection for the RSV will depend on estimated reductions in their cost, weight and complexity in coming decades.

Emergency Brakes

The specifications formulated for this mode required special attention because accident causal factors studied revealed that brake component failures and malfunctions occur quite frequently in the list of factors attributed to the vehicle. The brake system performance under two

SYSTEM	ANTILOCK SYSTEM IN A FOUR WHEEL VEHICLE	STABILITY			STEERABILITY	BRAKING CAPABILITY	APPROXIMATE ADDITIONAL COST - %
		STRAIGHTLINE BRAKING	BRAKING ON A TURN	BRAKING ON SPLIT COEFFICIENT SURFACE			
1. NO CONTROL		CRITICAL	CRITICAL	YAW MOMENT	NONE	ACCORDING TO SLIDING COEFFICIENT OF FRICTION	0
2. ONE CHANNEL*	 SELECT LOW	GOOD	CRITICAL	GOOD	NONE	OPTIMUM FRICTION ONLY ON REAR WHEELS	30
3. TWO CHANNEL	SELECT LOW 	GOOD	VERY GOOD	VERY GOOD	GOOD	UNSATISFACTORY ON SPLIT COEFFICIENT SURFACE	60
4. TWO CHANNEL	SELECT HIGH	GOOD	GOOD	GOOD	SATISFACTORY	GOOD	60
5. THREE CHANNEL		GOOD	GOOD	GOOD	GOOD	GOOD	85
6. FOUR CHANNEL		GOOD	GOOD	GOOD	GOOD	OPTIMUM	100

* Number of channels indicates number of [illegible]

Table 5-3. Braking Performance Study System Configurations

System	Front Metering Valve	Front Proportioning Valve	Rear Proportioning Valve	Antilock Modulator
1	None	None	None	4-wheel
2	Fixed	None	Fixed F/R**	2-wheel rear
3	Fixed	None	Fixed F/R	None
4	Fixed	None	Variable F/R	None
5	Fixed	Variable R/L*	Variable F/R	None
6	Fixed	Variable R/L	Variable F/R	2-wheel rear

*R/L = Right/Left

**F/R = Front/Rear

Table 5-4. Brake System Comparison

System Number	Overall Performance	Cost, Weight and Complexity
1	Very good	Higher
2	Good	Lower
3	Fair	Lower
4	Fair	Lower
5	Good	Higher
6	Very good	Higher

types of failures is covered under emergency brakes. Failure warnings are covered in other sections of the specifications. The two failures covered are (1) booster failure, and (2) leakage type failure.

Performance under both failure conditions is specified for the RSV at a higher level than the guideline specifications. The rationale and justification for higher level of failure mode performance follow.

Booster Failure. The 4-passenger RSV sedan with a curb weight under 3000 lbs represents a borderline case when a selection is to be made between manual brakes and power-assisted brakes. Limpert, et al, have shown by [8] analysis that a passenger car having manual brake system and a total weight of approximately 3000 lbs, represents a limit vehicle which can still be safely decelerated by manual brake application. Hence, an RSV may or may not have power-assisted brakes depending on its final curb weight, loading conditions, load distributions and the basic brake system design chosen. If power assist is incorporated, the gain required will not be very high and the substantially higher level of performance specified for RSV (200 ft) over the guideline specification (300 ft) is certainly justified, and should produce improved safety performance without undue weight or cost penalty. If power assist is not used, this type of failure mode is eliminated and to that extent, vehicle safety is increased.

A review of booster failure performance data for cars in 1973 [5] model year shows that several of the small vehicles (Volkswagens, Datsun, Comet, Pinto, etc.) do not have power-assisted brakes and hence, booster failure performance is not listed. Those small vehicles which have power-assist (Mazda, Volvo, Cortina, Fiat, etc.) show a booster failure stopping performance at a slightly lower level than is had with normal braking as shown in the following table.

BRAKING PERFORMANCE FOR 1973 SMALL CARS

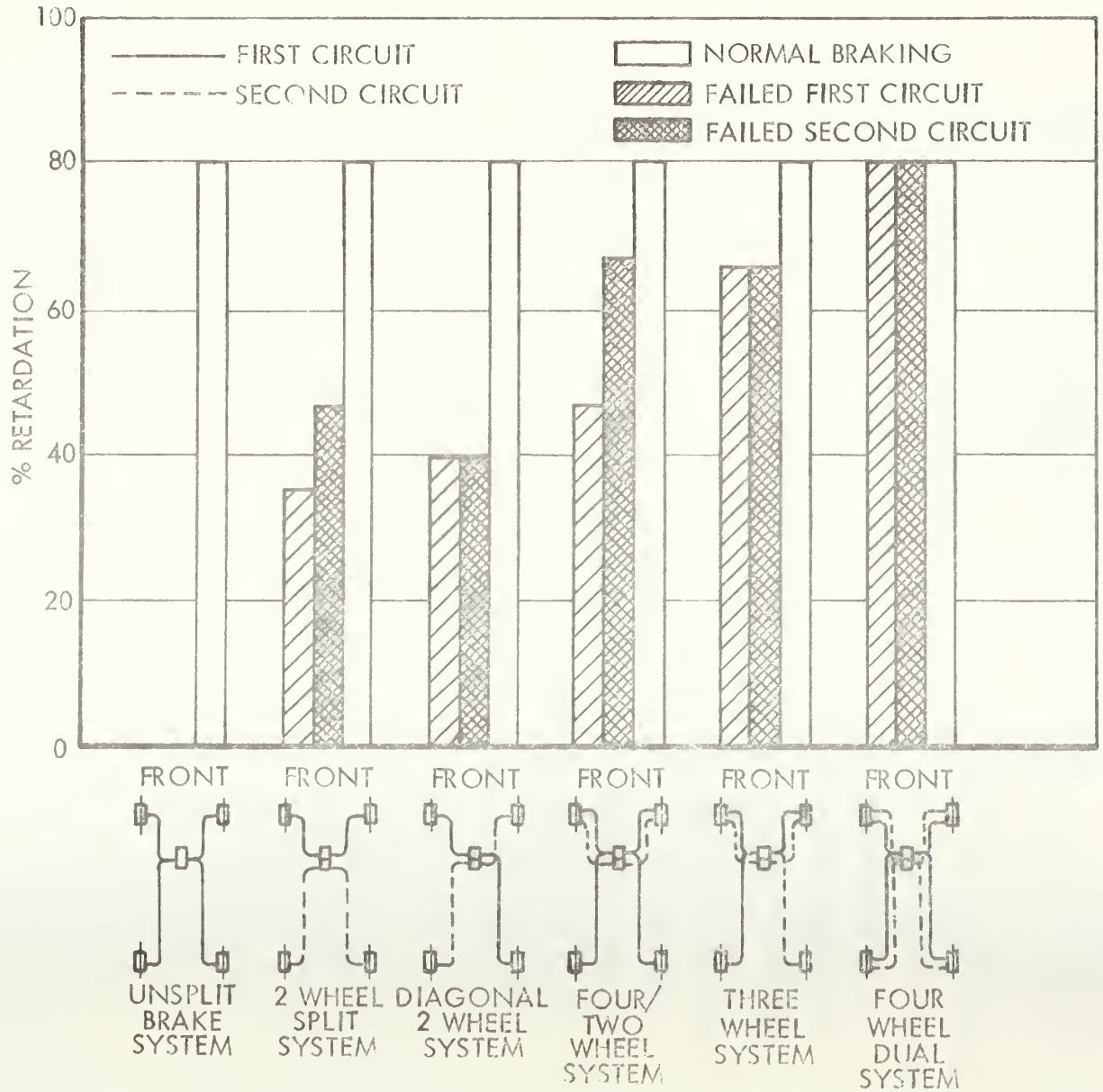
Vehicle	Curb Weight (lbs)	Stopping Distance from 60 mph	
		Normal Braking (ft)	Booster Failure (ft)
Mazda RX-2	2355	171	187
Volvo 142E	2681	185	226
Cortina	1860	212	217
Fiat 124	2038	172	182
Capri	2333	180	192

Leakage Type Failure. Leakage or failure of a pressure component of the brake system results in loss of braking capability. Since 1970, brake circuit splitting has been mandatory in the U.S. to ensure at least partial performance in the event of such a failure in one of the circuits. The probability of failure occurring in both circuits simultaneously is regarded as remote. However, the probability of failure occuring in either one of the two split circuits is regarded as equal; the specifications take this into account and minimum partial failure performance is set for failure in either system.

There are several ways in which the brake circuit splitting can be achieved. Four common ways of circuit splits and the resultant theoretical partial failure performance are shown in Figure 5-1; unsplit and 4-wheel fully split brake systems are included for comparison. The indicated performance was computed for a vehicle with the following properties: [16]

Weight distribution: Front 48.5%, Rear 51.5%
Ratio of height of center of gravity to wheelbase: 0.211
Percentage of total brake force at rear axle: 28.8%

The results presented in Figure 5-1 show the 4-wheel system as having the best partial failure performance. However, this performance may be somewhat offset if overall probability of a certain failure is taken into account; with the additional pressure lines and connections required by this


100
80
60
40
20
0
% RETARDATION
FIRST CIRCUIT
SECOND CIRCUIT
NORMAL BRAKING
FAILED FIRST CIRCUIT
FAILED SECOND CIRCUIT
FRONT
FRONT
FRONT
FRONT
FRONT
FRONT
UNSPLIT BRAKE SYSTEM
2 WHEEL SPLIT SYSTEM
DIAGONAL 2 WHEEL SYSTEM
FOUR/ TWO WHEEL SYSTEM
THREE WHEEL SYSTEM
FOUR WHEEL DUAL SYSTEM

system, the probability of failure will certainly arise. The RSV performance specifications do not favor any one system. On the contrary, manufacturers are required to make a design decision based on overall vehicle configuration satisfying performance requirements and assessing the weight-cost-failure probability penalties associated with each system.

The basic weight distribution (fore/aft) of a vehicle also plays an important role in the partial failure performance of vehicles. This is evident in the brake performance data on 1973 vehicles presented in Reference 6. The results are not repeated here, but the conclusions drawn from the data are as follows:

a. Rear-heavy vehicles like the Volkswagen, or typical station wagons, show relatively better partial failure performance than do the front-heavy vehicles like the Audi or Peugot.

b. The Volvo with its 3-wheel brake split system has, as expected, a partial failure brake performance much better than that of other vehicles with either 2-wheel or diagonal split brake circuits.

The influence of weight distribution and various types of split circuits was considered in establishing RSV specifications to ensure that the constraints they impose will enhance performance.

Heat and Water Fade Performance

The heat and water fade performance is specified at 10% above that in the guideline specifications. Developments underway on materials for brake discs and linings, better design to promote cooling, and the increased use of disc brakes in place of drum brakes as shown below, indicate at least a 10% improvement in heat and water fade resistance in the coming decade. [17 thru 22]

PRODUCTION USE OF DISC BRAKES

Year	Unit X 1000	Percentage (%)
1969	1,507	18.2
1970	3,131	39.5
1971	4,537	60.0
1972	5,938	69.4
1973	8,598	87.3

Parking Brake

Parking brake performance as established in the guideline specification is at a reasonable and safe level and is retained at the same level for the RSV. Similarly, the effort for foot and hand controlled actuation of the brakes is retained at the guideline levels.

Vehicle Jacking

Vehicle jacking requirements as specified in the guideline are retained. If run-flat tires are used, they will have to meet the performance specifications which are covered in a subsequent section on wheels and tires.

2.1.2 Steering

RSV steering performance is specified for the following three basic maneuvers:

1. Steady state yaw response
2. Transient yaw response
3. Returnability

The above maneuvers were established during the initial phases of the ESV program and therefore, a sizeable body of test data is available on the performance capabilities of various sizes of vehicles, ranging from small size 1500 lb ESV's to the first generation full-size ESV's. Moreover,

these three maneuvers adequately define the vehicle's basic dynamic performance, and are retained to define RSV steering performance.

The descriptions of the individual parameters in the performance specifications for steering follow.

Speed of Maneuvers

Steady State Yaw Response. Steady state yaw response is at speeds from 25 to 70 mph. Below 25 mph, the vehicle must be negotiating an extremely sharp turn to lose its lateral adhesion. Moreover, under 25 mph, braking can be effectively used to avoid an accident. Hence, speeds in this lower range are not considered. Twenty-five to 70 mph is a wide enough range of speeds to define the majority of current U.S. driving patterns; this range is predicted to remain unchanged through 1985. Four speeds, namely, 25, 37.5, 50 and 70 mph are specified within this range for the RSV. The IESV specifications called for three speeds in the range. It is felt that four speeds will more precisely define the steady state yaw response curve.

Transient Yaw Response. Transient yaw response of a vehicle is influenced by the speed of maneuver. The intent of the performance requirement is to restrict the transient yaw gain overshoot or undershoot within stable limits; hence, a maximum overshoot for 70 mph and a maximum undershoot for 25 mph is specified. The transient yaw response at other speeds between 25 and 70 mph will fall within these two limits, and only the limit speeds are specified.

Returnability. Within the operating speed range of 25 to 70 mph, the steering input required to produce the same steady state lateral acceleration decreases as the vehicle speed increases. Returnability performance is specified at two speeds where the steering input required for specified 0.4 g lateral acceleration is reasonably large; the two specification speeds are 25 and 50 mph.

Lateral Acceleration Levels

The basic lateral acceleration level, specified at 0.4 g, has been retained. It is judged to be a reasonable value because of the following three considerations:

1. The lateral performance of a vehicle is linear up to 0.3 g lateral acceleration. Above 0.3 g, the performance is nonlinear. Hence, the selected of 0.4 g is in the more critical nonlinear range.

2. The design of roadways and selection of traffic speed limits are generally standardized to produce 0.1 to 0.15 lateral accelerations under normal driving conditions. On the other hand, the vehicles on the road usually have maximum lateral acceleration capabilities of 0.55 to 0.7 g's. Hence, the selected level of 0.4 g is at the mid-point between normal operating acceleration and the vehicle's maximum capability.

3. The table that follows shows the radius of curvature of the path necessary to produce 0.4 g lateral accelerations at four speeds in the operating range of 25 to 70 mph. Under these conditions, the driver-vehicle combination can easily reach a level of 0.4 g lateral acceleration in an emergency accident avoidance maneuver.

RADIUS OF CURVATURE TO PRODUCE 0.4 g LATERAL ACCELERATION

Speed, mph	Radius of Curvature, Feet
25	100
37.5	225
50	417
70	819

The lateral acceleration of 0.4 g is specified with a tolerance of ± 0.02 g's. This was found to be a reasonable tolerance limit during Dynamic Science's testing of ESV's and is retained for RSV specification.

Steering Input Conditions

A vehicle's transient yaw response depends on the rate of steering input application. A value of not less than 500 degrees/sec is specified as a reasonable value in an emergency situation.

There is generally a time delay between steering input and the vehicle's transient yaw response. Moreover, the steering input itself, particularly at speeds below 25 mph, takes appreciable time. Therefore, for the purposes of standardization, the initial time, T_o, of transient yaw response is clearly defined in the transient yaw response requirement.

Performance Parameters

The basic parameter specified for steady state and transient yaw response is yaw gain, defined as follows:

$$\text{Yaw gain} = \frac{\text{yaw velocity - deg/sec}}{\text{front wheel angle - deg}}$$

This basic parameter, yaw gain, is multiplied by the vehicle's wheelbase in feet to define the steady state yaw response shown in the specification Figure II. The rationale for retaining this definition is as follows:

The neutral steer line of a vehicle is a function of wheelbase as shown in Figure 5-2. Since the RSV specifications do not specify any one wheelbase for the vehicle, yaw gain is multiplied by a to-be- determined wheelbase to define the yaw response and make possible the performance comparisons of vehicles with different wheelbases to the same scale.

The transient yaw response uses the percentage value of instantaneous yaw response to the baseline yaw response produced by the same vehicle at the same speed and under a steady state condition at 0.4 g lateral acceleration. (See Specification Figure III.)

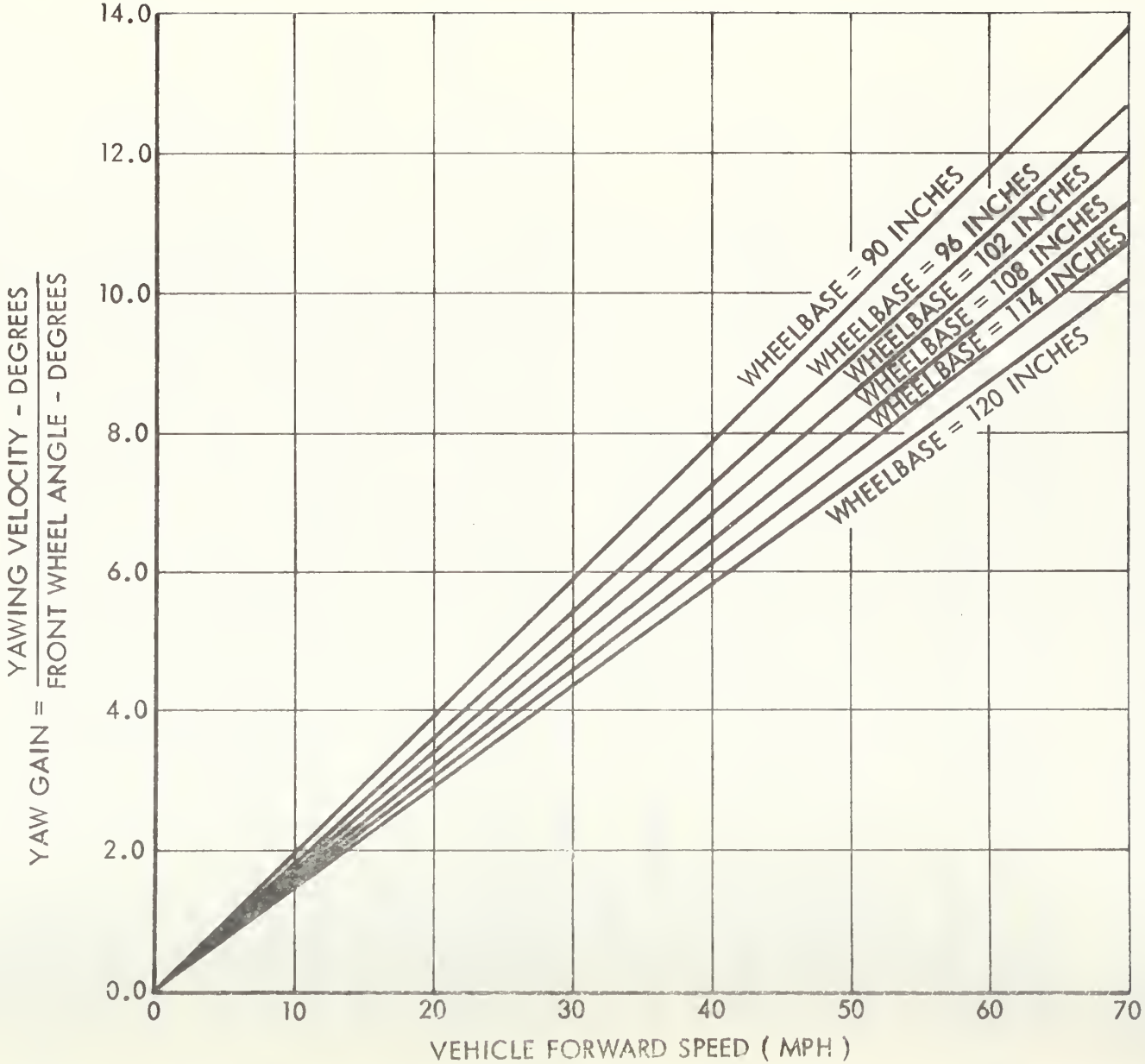


Figure 5-2. Neutral Steer Lines for Different Wheelbases

Yaw Response (Steady State)

Figure 5-3 shows the vehicle's two yaw response zones: namely, the understeer zone and the oversteer zone. The dividing line between these two zones is the neutral steer line. In the understeer zone, the vehicle is basically stable. Within this zone, as the vehicle's yaw response approaches its neutral steer line, stability is reduced, but the yaw response to steering input is quicker. Inside the oversteering zone, the vehicle has a finite critical speed above which it can go into an unstable mode; but overall, the vehicle response is faster than in the understeer zone. Several authors [24, 25] have commented upon the generally lesser degree of understeer characteristics of European type smaller vehicles as compared with a characteristically much higher degree of understeer designed in the larger U.S. vehicles. Part of the reason for this difference is the shifting of the neutral line resulting from differences in the sizes and wheelbases of the vehicles. The other part is due to different driving conditions existing in Europe and in the United States.

The RSV specifications account for these varying influences and the specified steady state yaw response envelope provides an excellent balance between stability and control of the vehicle.

Within the specification envelope, the shape of the curve is required to be concave downward to ensure that at higher speeds, some control will be compromised in favor of additional stability. Further, a concave shape will ensure that the vehicle will not go into oversteering at speeds above 70 mph. The requirement of the concave downward curve shape is also specified for lateral accelerations of above and below 0.4 g for the same reasons.

The RSV specifications require that steady state yaw response curves, obtained at lateral accelerations above and below 0.4 g, should move gradually below and above the 0.4 g basic steady state yaw response curve. This behavior is characteristic of an understeering vehicle. It is in keeping with the overall philosophy of providing more control under relatively less

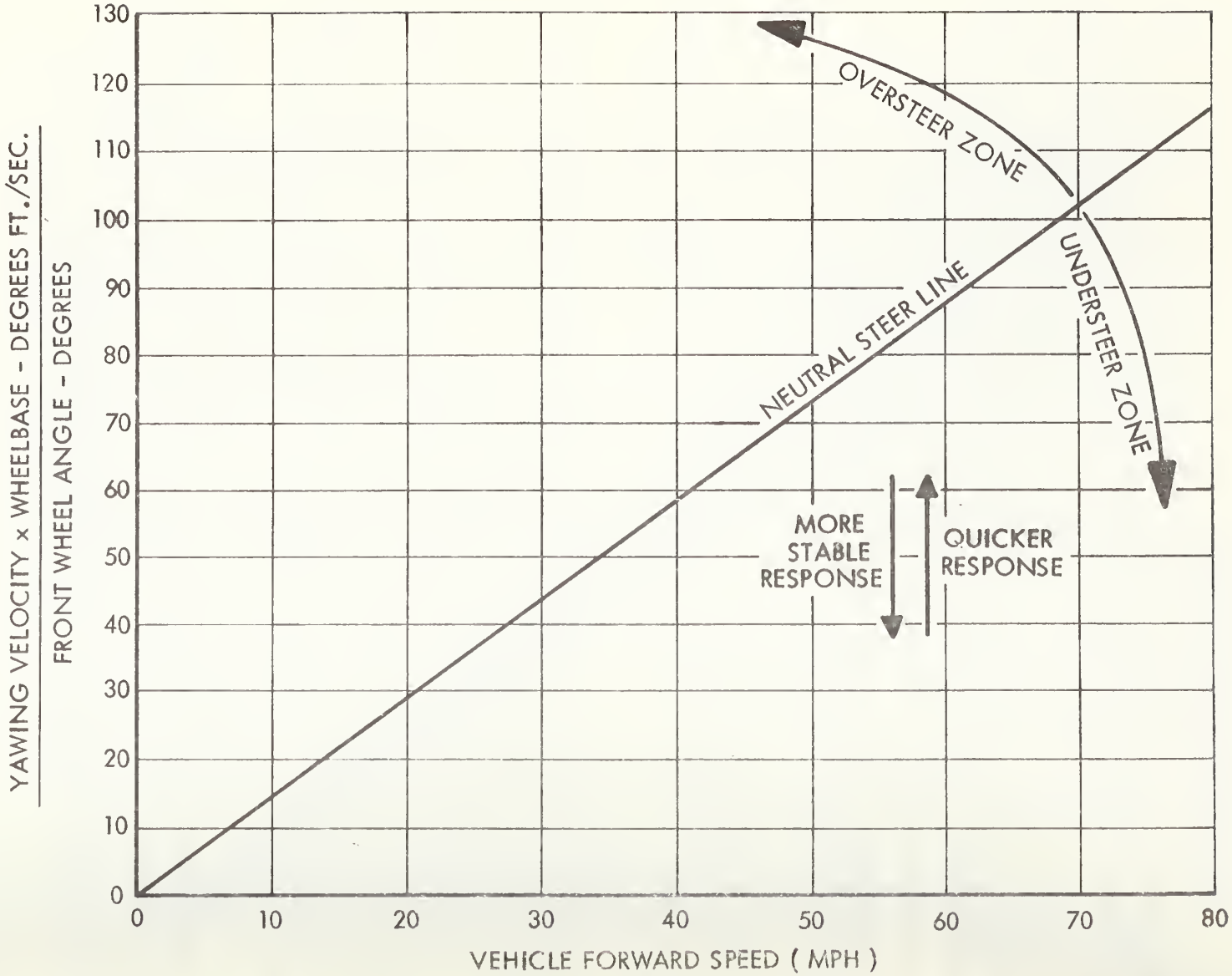


Figure 5-3. Steer Zones and Response Quality

critical conditions and higher stability at relatively more critical condition. The guideline specifications require some clarification on the applicability of 0.4 g performance envelopes to the response curves obtained at varying lateral accelerations. The RSV specifications clearly state that other curves need not be bound by the basic envelope which applies only to 0.4 g lateral acceleration.

In any case, AMF's Tradeoff & Integration Systems Studies program [15] indicated that as the basic steady state yaw response of the vehicle (at 0.4 g) moves towards the neutral steer line, the excursions of the response curves, at other than a 0.4 g lateral acceleration, are reduced. Since RSV has specification limits nearer to neutral steer line, the excursions of other than 0.4 g lateral acceleration curves should be rather limited.

AMF conducted a parametric study to assess the quantitative influence of various vehicle parameters on a vehicle's yaw response. The results [15] indicated that the fore/aft weight distribution of a vehicle plays a key role in its yaw response behavior. Tire inflation pressures also influence the vehicle's yaw response albeit to a lesser degree. Hence, these two parameters were considered in drawing specifications.

The steady state yaw response of an RSV is specified to be within the envelope shown in the Specification Figure II. It is possible that an RSV will exhibit a steady state yaw response just about on the boundary line under a full front compartment capacity load and design inflation pressures. The same vehicle, under 100% rated load condition and intentional or unintentional off-design inflation pressures, may show a steady state yaw response which is outside the limit boundaries.

This is of importance for RSV since the specifications are very close to the neutral steer line. Thus, an RSV under certain load conditions and tire inflation conditions may show oversteering response which can be unstable and unsafe.

There are two possible ways of formulating the specifications to ensure that the vehicle will not cross over into the oversteer zone. One way is to set the specifications well in the understeer zone so any migrations of

the steady state yaw response will still be inside the understeer zone. The other way is to select load and tire inflation conditions that will tend to make the vehicle oversteer and specify that the RSV will exhibit steady state yaw response within a specified envelope.

The first alternative has a drawback in that it will not allow certain vehicles to fully utilize their basic potential. For example, a basic front heavy vehicle will not be affected that much by 100% rated load and the consequent aft shift of the center of gravity. But, it will have to be within the specifications which are well in the understeer zone.

The specifications presented are drawn to address this problem by taking the best of both alternatives as follows:

1. The RSV steady state yaw response upper boundary is not a neutral steer line at all speeds. It is curved to be inside the understeer zone at higher speeds (see Figure II with the specifications).

2. One test condition is added requiring that the RSV have a steady state yaw response within the specification envelope under 100% rated load and with 120% design inflation pressures in the front tires and 80% design inflation pressures in the rear tires.

The inclusion of the above will assure dynamically stable performance under adverse load and inflation pressure conditions.

Yaw Response (Transient)

The RSV with its near to neutral understeer response should not exhibit excessive transient overshoot at 70 mph. The influence of understeer on the transient overshoot is discussed in an earlier AMF report. Based on this [15] background, the upper limit of the transient yaw response curve (70 mph) is modified to allow a 150% steady state value of the yaw response. The test results of the Toyota and Nissan ESV's show that they exhibit performance within the RSV limit even though they met earlier steady state yaw response limits (see Figure 5-4).

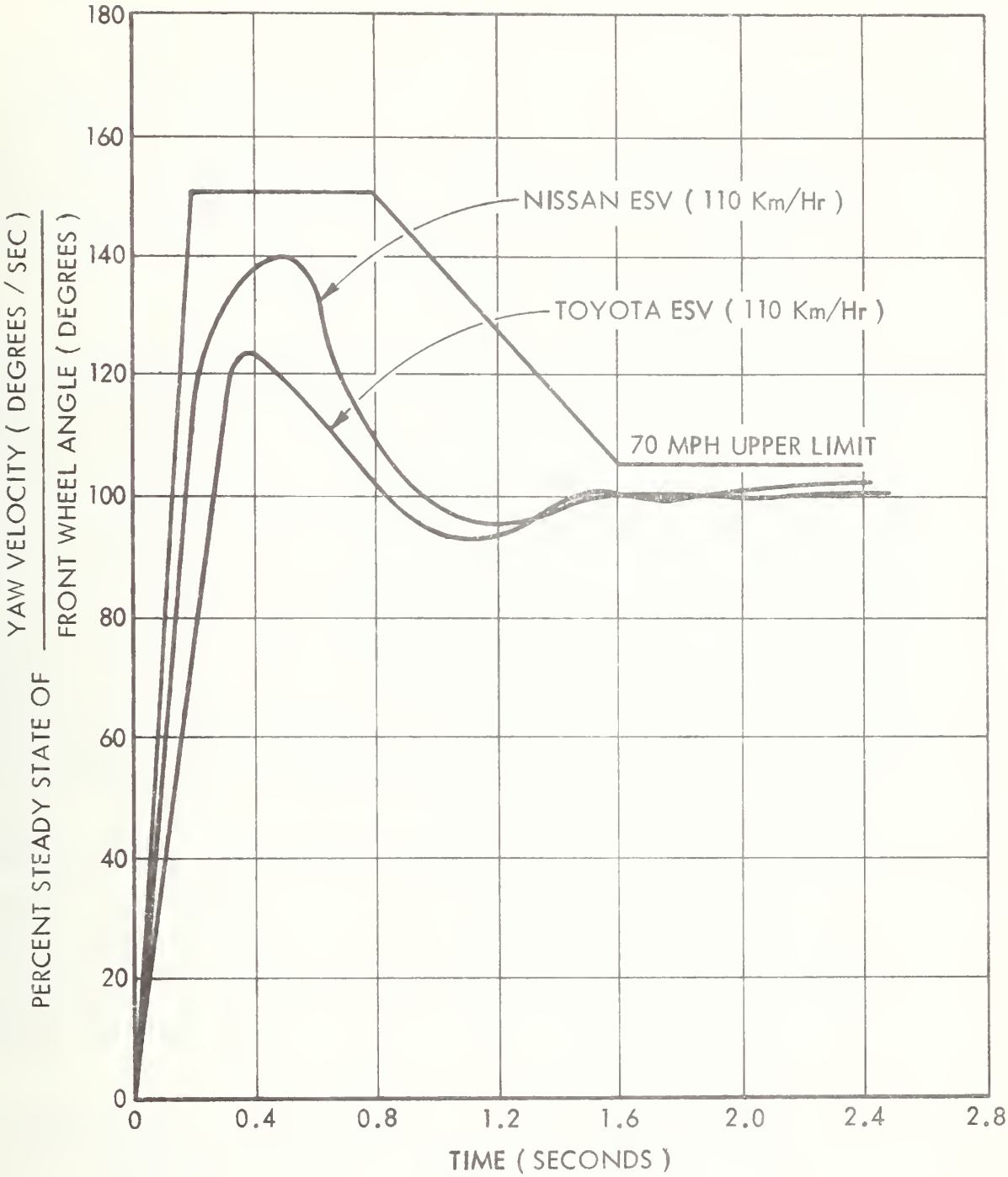


Figure 5-4. Nissan and Toyota ESV Transient Yaw Response Performance

The lower limit applicable to the 25 mph maneuver is slightly modified to accommodate the slow rising response of the smaller size RSV's.

The guideline requirements for the time allowed to dampen the transient overshoot are retained; 1.6 seconds is a reasonable period to dampen the transient excusion to within ± 5% of the steady state value.

Returnability

Returnability is a measure of the self-correcting capability of the vehicle's steering system in a transition from a circular path to a straight ahead path. A smooth, well damped and fairly quick transition from one steady state (curved path) to other steady state (straight ahead) is the performance goal. RSV's meeting the specifications will avoid characteristic unsafe responses such as extreme sluggishness, hard kickback of the steering, and oscillatory or oscillatory divergent transient response.

From ESV experience, it is known that steering wheel mounted air- [26
bags can increase the moment of inertia of the steering system and result 27
in a sluggish returnability performance. Hence, the returnability performance is set at a fairly high requirement to ensure that attention is given to this area of design.

The required performance is specified for the following two parameters:

1. Yaw Rate. From initial condition of 50 mph and 0.4 g lateral acceleration, the yaw rate should be damped to less than 4 degrees/sec within two seconds. From 25 mph, the yaw requirement is 1 degree/sec. These are fairly stringent but feasible conditions as indicated by the performance of the Toyota and Nissan ESV's shown in Figure 5-5.

2. Relative Heading Angle. The requirements of heading angle as defined in the guideline specification are adequate to ensure safe behavior and are retained for RSV. The upper limit of 25 mph performance provides for a transient time of 1.4 seconds and within that time, a transient overshoot of 3 degrees, or 25% above the steady state upper bound of 12 degrees,

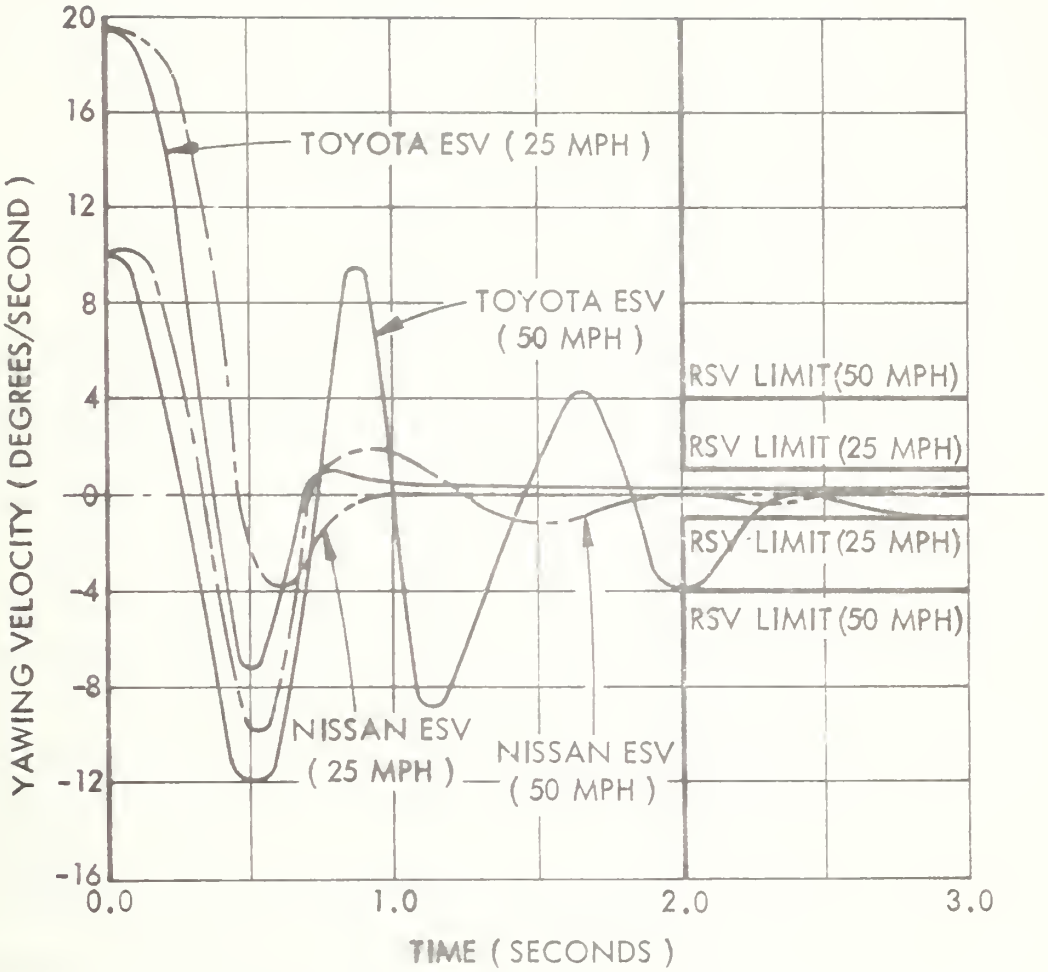


Figure 5-5. Toyota and Nissan ESV Returnability Performance. Yawing Velocity at 25 MPH (40 Km/h) and 50 MPH (80 Km/h)

is allowed. This is a reasonable performance requirement. The upper limit of performance for 50 mph does not allow for a transient overshoot. The lower performance limit is the same for both specification speeds. Toyota and Nissan ESV performance, shown in Figure 5-6, indicates the feasibility of this requirement.

2.1.3 Handling

The handling performance of the RSV is specified under three main categories, as follows:

1. Lateral Acceleration. The vehicle's minimum lateral acceleration capabilities are specified for five combinations of front/rear tire inflation pressures. The minimum lateral acceleration performance is also specified for wet pavement and design tire inflations.

2. Control at Breakaway. This maneuver is designed to quantify the vehicle's capability to respond to a driver control input and to recover from an "out of control" mode as a result of exceeding its maximum lateral acceleration limit. The other response of interest is the vehicle's capability to recover safely from an "out of control" mode when the throttle is closed (normal driver reaction after losing control).

3. Directional Stability. These maneuvers are designed to test the vehicle's directional stability and control characteristics under the influence of non-vehicular external disturbances. Cross wind gusts and pavement irregularity are the two external disturbances selected as typical of what an RSV will experience in its normal operation.

The description of individual parameters in handling performance specifications follows.

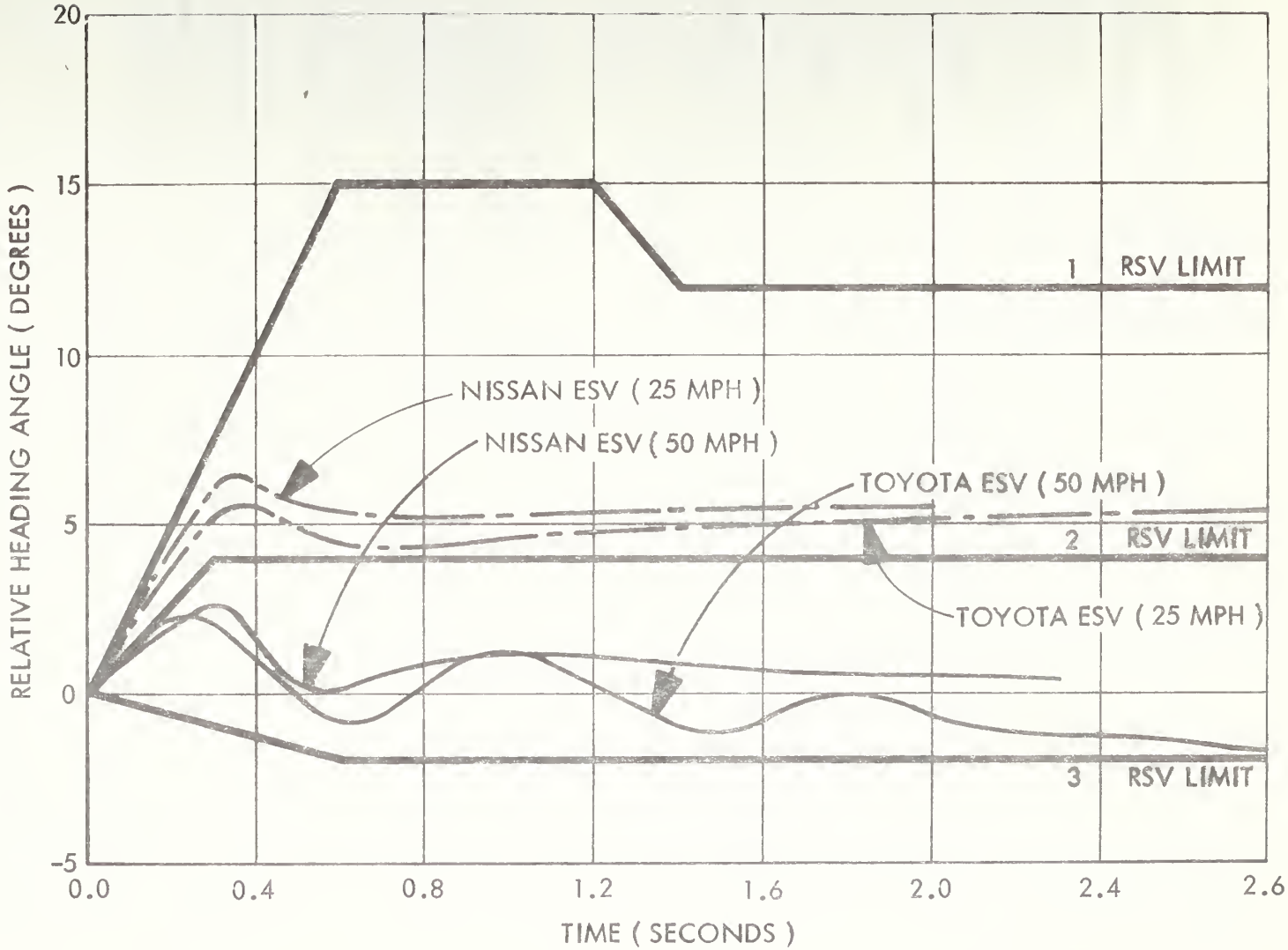


Figure 5-6. Toyota and Nissan ESV Returnability Performance Relative Heading Angle at 25 MPH (40 Km/h) and 50 MPH (80 Km/h)

Skid Pad Size

The maneuver associated with lateral acceleration performance is specified to be conducted on a skid pad of 100 feet radius. Lateral acceleration performance can be tested either by increasing the vehicle speed or by reducing the radius of curvature of the path. It was decided to specify the standard 100 foot radius skid pad for this performance. This has been a test practice for many years and since wet pavement performance is involved, the test program becomes manageable with the use of just one skid path.

Performance for control at breakaway is specified on two skid pads, one with a 100 foot radius and one with a 225 foot radius. It is felt that this critical performance should be specified at the moderately high level of speed associated with the 225 foot radius in addition to the 100 foot radius path and lower speed. The corresponding speeds cover the speed range of 30 to 45 mph which are deemed to be adequate for this performance.

Tire Inflation Pressures and Pressure Combinations

The analysis of accident causal data during the program definition task revealed that improper tire inflation pressure is very commonplace as a vehicle related factor. Accordingly, the RSV lateral acceleration performance is specified for the five combinations of front/rear tire inflation pressures on dry pavement shown in Table II of the specifications. The design value and variations around the design value of $\pm$ 20% inflation pressures are used for the front and rear tires. It is felt that vehicle's tire inflation pressure can be easily off 20% without a driver noticing it or feeling its influence on the ride and this variation can easily be the range of accuracy of cheap tire gages. The five combinations selected will tend to add oversteer or understeer to the basic steer characteristics.

Steering Correction

The permissible steering correction is restricted to 10 degrees of total steering movement. This minor adjustment is usually necessary to

maintain the circular course under vehicle acceleration and normal pavement roughness conditions. Steering control under this correction can still be considered as a fixed control.

Lateral Acceleration

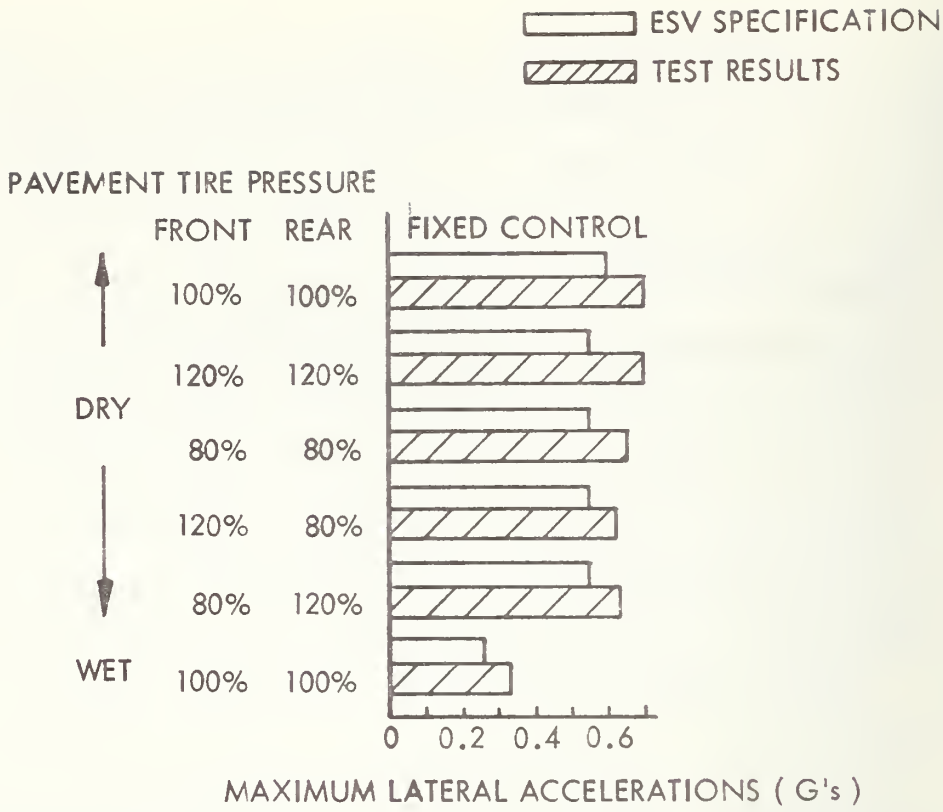
The minimum lateral acceleration performance specified for the RSV is kept at a level which represents a reasonably high, but not excessively high, degree of performance. The rationale for this level follows.

1. It is a human tendency on the part of those who crave performance to push a vehicle to its limits. A higher vehicle performance limit demands a much higher degree of skill from drivers who push it to limit conditions. The higher speeds existing under such higher performance limits compound the safety problem by allowing much less driver reaction time for corrective action. Therefore, from an overall safety viewpoint, the levels with a moderately high degree of performance are more appropriate to an RSV.

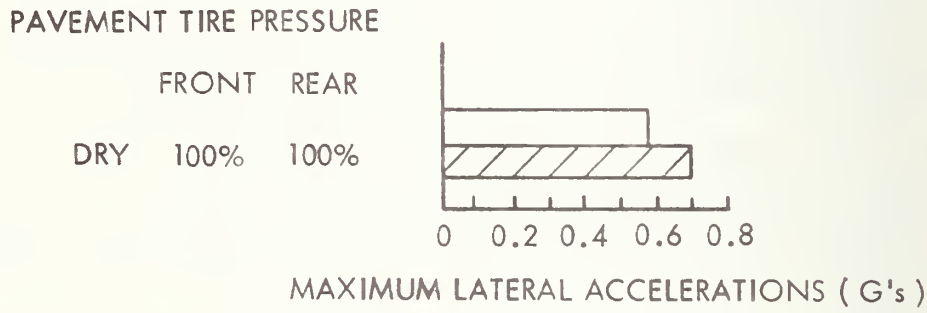
2. The lateral characteristics of a tire are nonlinear above a 0.3 g lateral acceleration. Beyond a certain peak level (above 0.3 g lateral acceleration), a reversal of lateral characteristics can occur. Hence, if excessively high lateral acceleration demands are placed on the vehicle, the possibility exists that this high demand can seriously affect the vehicle's capability to recover control once the limit is exceeded.

3. It is reported by German accident investigators that high performance Porsche's are overinvolved in accidents in Germany. Even though the referenced evidence is inconclusive, the conclusion drawn seems logical and noteworthy. [28]

The Toyota and Nissan ESV's exceeded the performance specified for the RSV by considerable margins as shown in Figure 5-7. The larger first generation ESV's also had no trouble meeting the same minimum lateral acceleration requirements. Christie has reported on the basis of cornering [14, 29] [30]



(a) TOYOTA ESV



(b) NISSAN ESV

Figure 5-7. Toyota and Nissan ESV Maximum Lateral Acceleration Performance

and chicane (lane change maneuvers) tests on a number of vehicles that smaller vehicles have an inherent potential for higher performance on dry surfaces as compared with larger vehicles.

Taking these facts into account, the minimum lateral acceleration performance for the RSV is set at a level which is slightly higher than that specified in the guidelines. This level is high enough to utilize the vehicle's potential and to promote operational safety; and yet, it is not so excessively high as to put heavy demands on the driver's skill and jeopardize safe operation under limit conditions.

Control at Breakaway

The requirement to regain the original vehicle path within 4 seconds after initiation of the control at breakaway maneuver is retained as it was specified in the guidelines. The RSV is required to have a steady state yaw response which will be closer to neutral steer line than would be the case for larger vehicles, and will provide the RSV with relatively quicker yaw response. On the other hand, a 10 foot radially outward movement of the smaller RSV may result in a higher heading angle change (as compared with larger wheelbase vehicles) and require a larger steering correction to regain original path. Hence, the time limit for regaining its initial path is left at 4 seconds.

Directional Stability

The specifications for directional stability address RSV performance under non-vehicular external disturbance inputs. A safe vehicle should be able to negate the influences of minor external disturbances and maintain its intended path without any major driver action. Examples of such minor external disturbances are: (1) slight lateral slope or camber of the road, (2) low speed side winds, and (3) minor irregularities of the pavement. Current passenger cars, with their inherent self-centering capability and with only minor steering corrections by the driver, can easily handle these disturbances.

Safety problems can arise when high level external disturbances are present. The RSV specifications address higher levels of two external disturbances to provide vehicle stability within the capabilities of driver-vehicle steering corrections. The two fairly severe disturbances selected for specifications are:

1. Cross wind gusts of 50 mph.
2. Pavement irregularity, one inch in height and at an angle of 30° to the vehicle path.

The descriptions of the two parameters, maneuver speeds and course deviation, associated with directional stability follow.

Maneuver Speeds. The preceding discussions on a vehicle's steady state and transient yaw responses indicated that a vehicle exhibits higher yaw gain at higher speeds; the same is true for transient yaw gain overshoot. Hence, it is obvious that the influence of external forces is more critical at higher speeds. Therefore, the required directional stability performance is specified at the higher speed levels of 44 ft/sec (30 mph), 73.3 ft/sec (50 mph), and 102.7 ft/sec (70 mph).

Course Deviation. The vehicle's dynamic behavior is closely linked with its steady state and transient yaw response characteristics. The path deviations exhibited by understeering, neutral steering and oversteering vehicles under the influence of a side wind force are shown in Figure 5-8. Under this force, a neutral steering vehicle continues on a new straight path and heads into the disturbing force, and the understeering vehicle takes a curvilinear path away from the disturbing force. The oversteering vehicle exhibits the least path deviation and the understeering vehicle exhibits the most path deviation; the exact amount of path deviation depends on the degree of steady state oversteer or understeer the vehicle has.

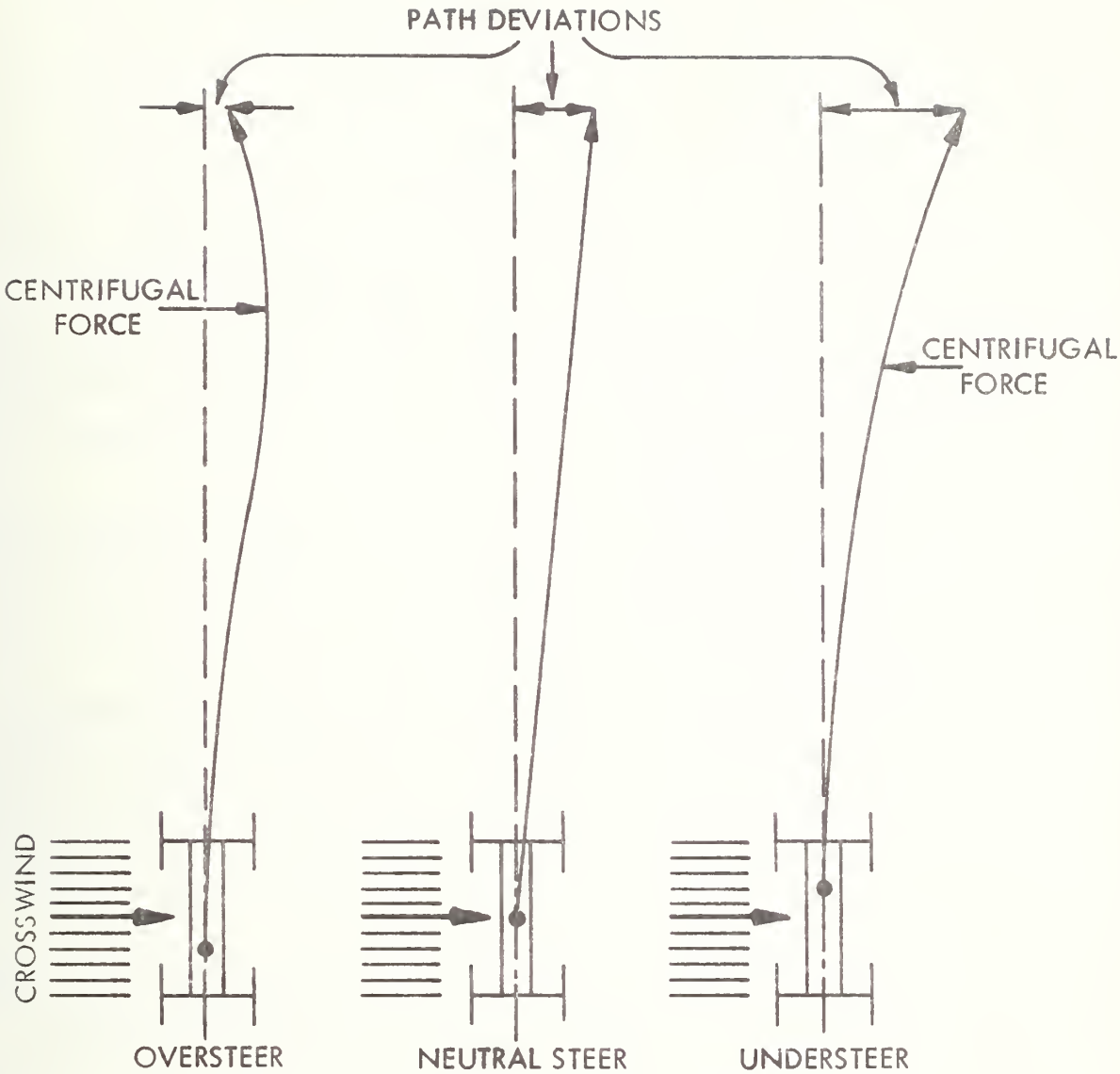


Figure 5-8. Effect of Crosswind on Three Types of Vehicles

Since gusts of side winds are being considered, the transient yaw response behavior of the vehicle also becomes an important factor. Generally, within the understeer zone, the higher the degree of understeer, the larger is the transient yaw response overshoot. Thus, in the case of a basically understeering vehicle, its path deviation under side wind gusts is magnified as a result of characteristically higher transient yaw overshoot.

As shown in Figure 5-8, an oversteering vehicle seems to exhibit a stable behavior if path deviation only is taken into account. However, it can be seen that as a result of its new curvilinear path, it generates a centrifugal force that acts in the same direction as the side force and compounds the problem. An understeering vehicle, on the other hand, generates a centrifugal force that opposes the side wind and tends to negate the side wind effect.

The RSV specifications call for steady state yaw response in the understeer zone towards neutral steer line and therefore, the RSV will not exhibit excessive path deviations as a result of side wind gusts. At 70 mph, the maximum allowable deviation is four feet.

Figure 5-9 shows the results of Nissan and Toyota ESV accident avoidance performance tests with the RSV specifications shown for reference. As indicated, both ESV's show much less path deviation than the specified performance limit. The performance boundary is shown concave upwards so that a reduction in speed will inherently reduce the path deviation. [29, 14]

The path deviation limit of one foot is the same as in the guideline specification for pavement irregularity sensitivity performance. Since the RSV is a small size vehicle, the one foot deviation limit is reasonable and attainable as indicated by the Toyota and Nissan ESV pavement irregularity performances shown in the table that follows.

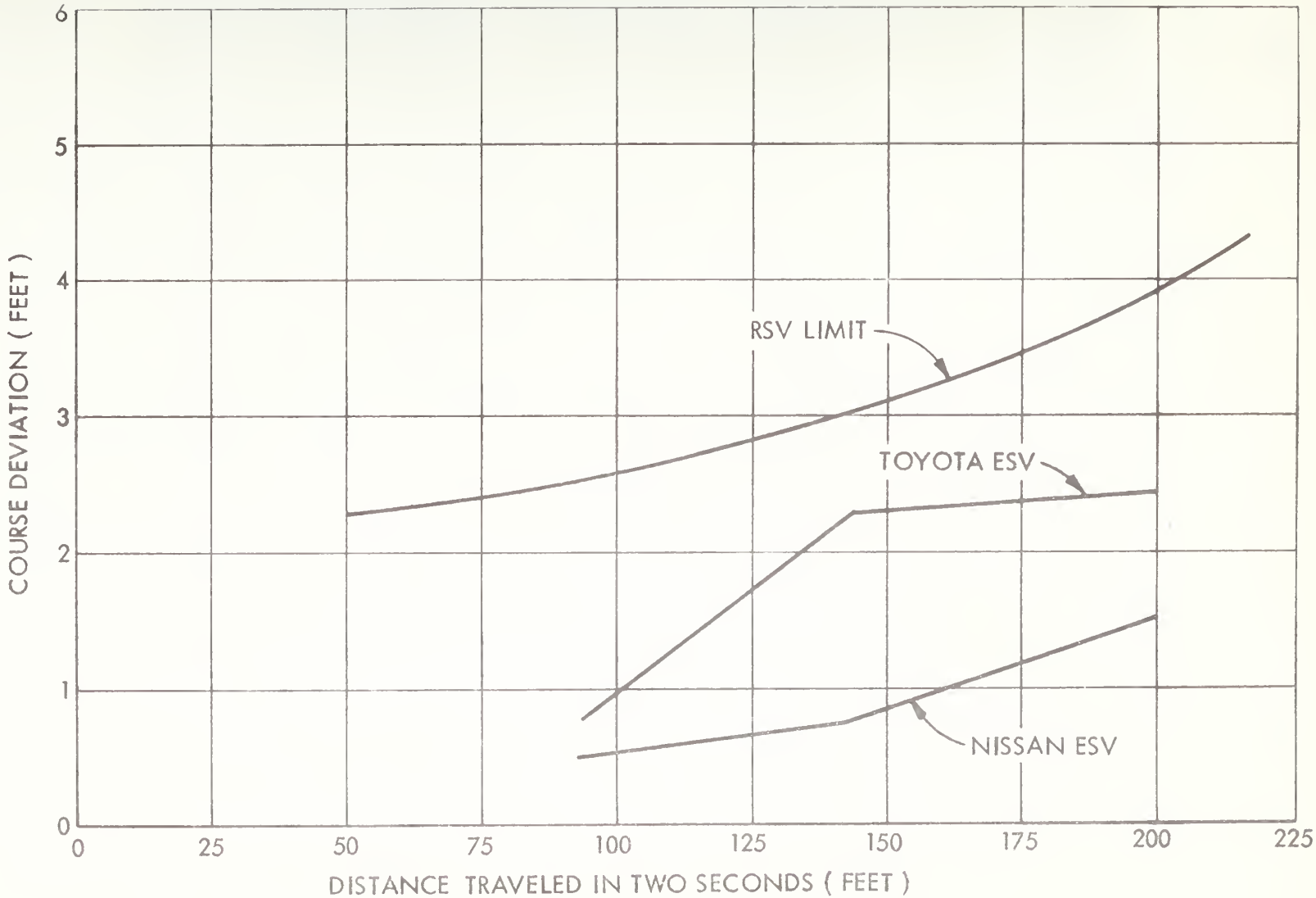


Figure 5-9. Allowable Course Deviation versus Distance Traveled

PAVEMENT IRREGULARITY SENSITIVITY PERFORMANCE

Vehicle	Path Deviation in Feet at Speeds of 30 mph	50 mph	70 mph
Toyota	0.25	0.16	0.23
Nissan	0.57	0.57	0.57
RSV Specification	1.0	1.0	1.0

Steering Control Sensitivity

The discussion of the steering control sensitivity specifications, part of directional stability, are treated separately as driver corrections and vehicle control depend on the amount of feedback or "feel" the driver has from the steering system rather than non-vehicular external factors.

The requirement that at least 5 in-lbs of torque at the steering wheel be required to cause a vehicle yaw rate of 2 degrees/sec ensures that the driver will have sufficient "feel" at the steering wheel to control the vehicle effectively. This requirement also reduces the chances of over-correction on the part of the driver under panic situations.

The second sentence in the steering control sensitivity specification applies only if the RSV is equipped with power-assisted steering and sets an upper limit of three for the ratio of "power off" to "power on" steering wheel effort. The specified RSV weight of 3000 lbs maximum is such that it is questionable if power steering is necessary. Since it is on the boundary between the power and manual types of steering, the specified ratio of three can be easily met. This lower ratio of three (compared with five specified in the guidelines) will ensure that enough steering effort is retained in "power on" mode to provide the driver with a safe level of "feel" for steering.

State of the Art Development

Appropriate to this section on dynamic stability is a summary of the state of the art developments termed variously as "silent co-pilot", [31, "adaptable steering", and "side wind compensator". The basic principle of 9] all these devices is the same; they sense the presence and influence of external distrubances like side wind and pavement irregularity and apply corrective steering inputs to counteract those forces. Consequently, both path deviations and driver effort are minimized. The side wind compensator reduces path deviations to about 1/3. Adaptable steering reportedly provides a high degree of vehicle controllability, requiring driver steering inputs that are fewer in number and smaller in magnitude than would be the case without this device.

The RSV specifications do not set such a high performance level to demand the inclusion of any such device; the inclusion of these devices is left to the discretion of the individual RSV manufacturer, based on considerations of enhanced safety performance and cost effectiveness.

2.1.4 Overturning Immunity

Rollover of a vehicle is one of the most violent automobile accidents in terms of occupant injury exposure. From the moment the rollover is initiated, the driver simply has no means of controlling the ensuing vehicle motion. Hence, the emphasis is on specifying adequate levels of overturning immunity to be designed into the vehicle.

The program definition studies projected that smaller vehicles (under 15] 3000 lbs) would continue to be over-represented in rollover accidents and that most of the rollovers would occur at speeds over 30 mph, particularly in rural areas.

J.W. Garrett reports that vehicle weight and tread width play a [33] major role in vehicle overturn; the smaller the weight and tread width of a vehicle, the higher are its chances of overturning. Similar results are [34] reported by Marsh, et al, from a study of 3000 CPIR cases. Their findings [35]

regarding size of the vehicle and speed of the accident substantiate the findings of the AMF and J.W. Garrett studies.

All studies result in the same conclusions; namely, that: (1) smaller vehicles are over-involved in overturning accidents, and (2) the largest proportion of overturning accidents occur at speeds higher than 30 mph. Hence, the RSV specification calls for overturning immunity at all speeds under any combination of braking and/or steering at any speed on a level, paved track. This means that the RSV will have to provide overturning immunity on a level paved track up to the limit of tire-to-pavement adhesion.

The specification includes two limit (extreme) load conditions for overturning immunity: the minimum load (driver only) and 100% rated load.

It is known that the suspension design of a vehicle plays a major role in overturning of a vehicle. Ervin, et al, report from their vehicle handling performance studies that suspension design and tire rolling-under influence vehicle overturning. Further, improper selection of shock absorbers or worn out shock abosrobers also increases the possibility of overturning. Hence, the two extreme load conditions specified for overturning immunity performance ensure that the suspension design addresses overturning immunity over the entire vehicle load range. This is particularly important for the smaller size vehicle where its load capacity is a larger proportion of the vehicle's curb weight than it is for larger vehicles, and the allowable static deflections of the suspension system are limited to much smaller values (2 to 3 inches). [57]

Two maneuvers are specifically required as a minimum to demonstrate overturning immunity. The first maneuver, slalom course traverse at a speed of 50 mph or above, will ensure that the buildup in the suspension forces as a result of side to side rolling will not induce overturning on a level paved road. The second maneuver involving steering and braking was formulated by HSRI. Their testing of 12 production vehicles showed that drastic steer and brake maneuvers resulted, in certain cases, in failure of suspension [57]

components, and tire deflation due to bead unseating. Hence, the drastic steer and brake maneuver is specified for RSV to minimize the possibility of these failure modes.

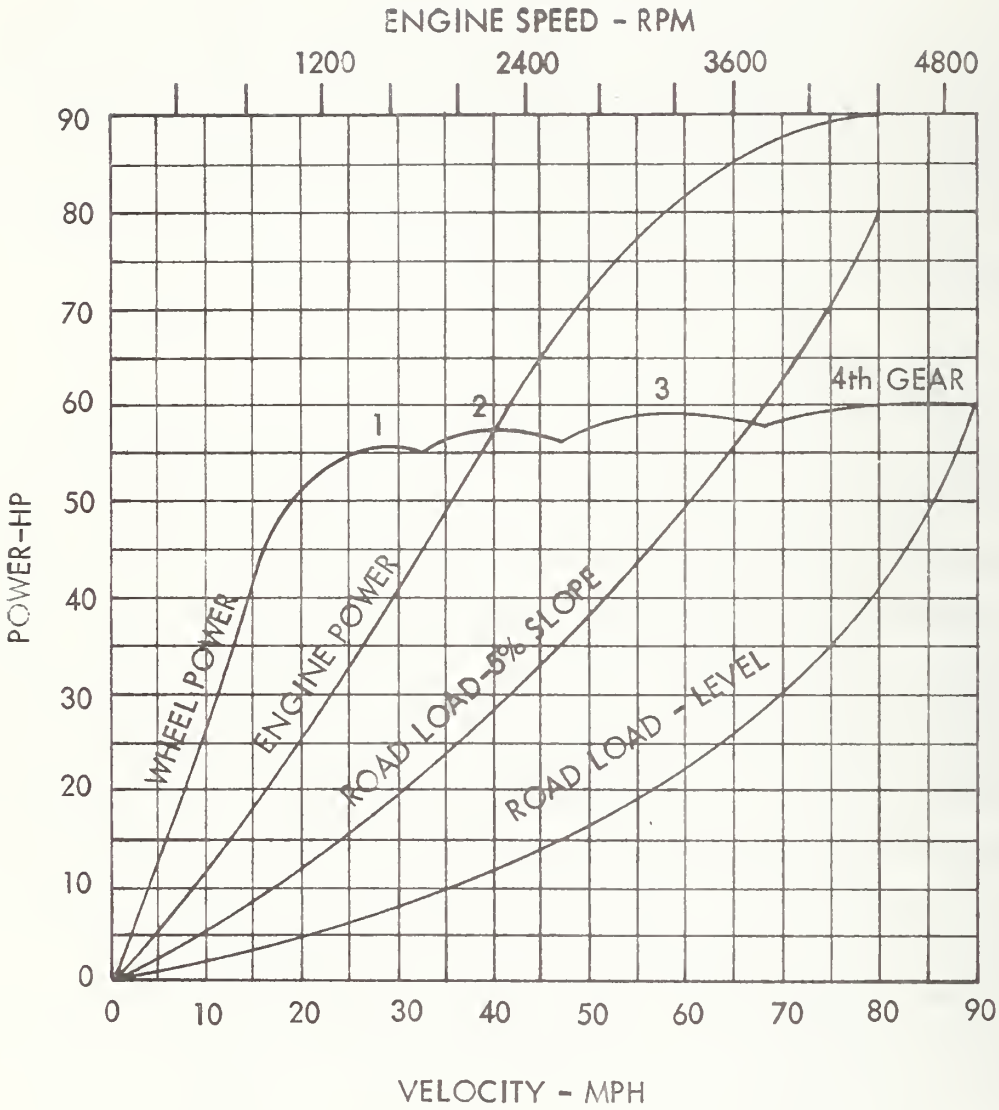
2.1.5 Power Plant System

The title of this section was changed from Engine and Driveline Systems to Power Plant System so as not to imply any restrictions on acceptable propulsion means and the elments of a power plant system are defined. The payload acceptable to power plant performance is also defined and is based on the average occupancy for most trips with average occupancy assumed to be two 50th percentile males with luggage.

Acceleration

The specified performance level is considered as the minimum acceptable level for the projected traffic environment and a 55 mph speed limit. The ability to merge with traffic and to pass moving vehicles safely is the prime consideration for acceleration performance. As far as acceleration performance is concerned, two differing arguments prevail. One is that drivers get into hazardous situations in which substantial acceleration capabilities are required to extricate themselves. The other is that drivers adjust to driving vehicles with lower acceleration performance; an approach which seems to be the safer mode of driving. The benefits derived from either levels of performance are difficult to assess since both are present in the current traffic environment and available accident data does not address the acceleration factors in accident involvements.

With the specified performance, the minimum required power output is shown in Figure 5-10. This power estimate is based on a conventional gasoline engine system which conditions the power with proper gear ratios to provide the required acceleration performance in each speed range. The power level is kept low to provide good fuel economy and in the high speed range, limit top speed.



VEHICLE CHARACTERISTICS:		
	TEST WEIGHT	3,275 LBS
	FRONTAL AREA	20 SQ. FT
	DRAG COEFFICIENT	0.4

Figure 5-10. RSV Power Requirements

The acceleration performance, shown in Figure 5-11, would be moderate with an instant acceleration of 6 mph/sec (8.8 ft/sec) at 20 mph and 3 mph/sec (4.3 ft/sec) at 40 mph.

Power Train

A generalized specification for the power train has been added to require efficient performance with any power plant system. Tires were included in the power train because of their relative importance in influencing ride, wear, stability, traction and power loss characteristics as shown in the table that follows.

TIRE PERFORMANCE AND HORSEPOWER LOSSES AT 50 MPH

Design Rating	Ride	Wear	Stability	Traction	Total HP Loss 2500 lb Vehicle
Standard 6.70-13 (bias ply)	100	100	100	100	6.0
Belted Radial	80	175	95	105	4.8
Special Compounding	80	140	95	90	3.8
Gauge Reduction	80	130	90	90	3.6
Reduced Deflection	75	140	95	90	2.8
Low Aspect Ratio	65	150	100	95	2.5

Lateral Force Influence

This requirement was retained primarily to cover power plant systems which are not used in current production vehicles. If a power plant system is based on a carburetor with an improperly designed float bowl, the fuel delivery could be reduced enough to indice momentary engine stalling under lateral forces. Most current carburetors have the float bowl located in such a manner that the fuel delivery is not affected by an applied lateral force. Where electronic fuel delivery systems are used, these are less susceptible to lateral force effects on fuel delivery. Since most of the

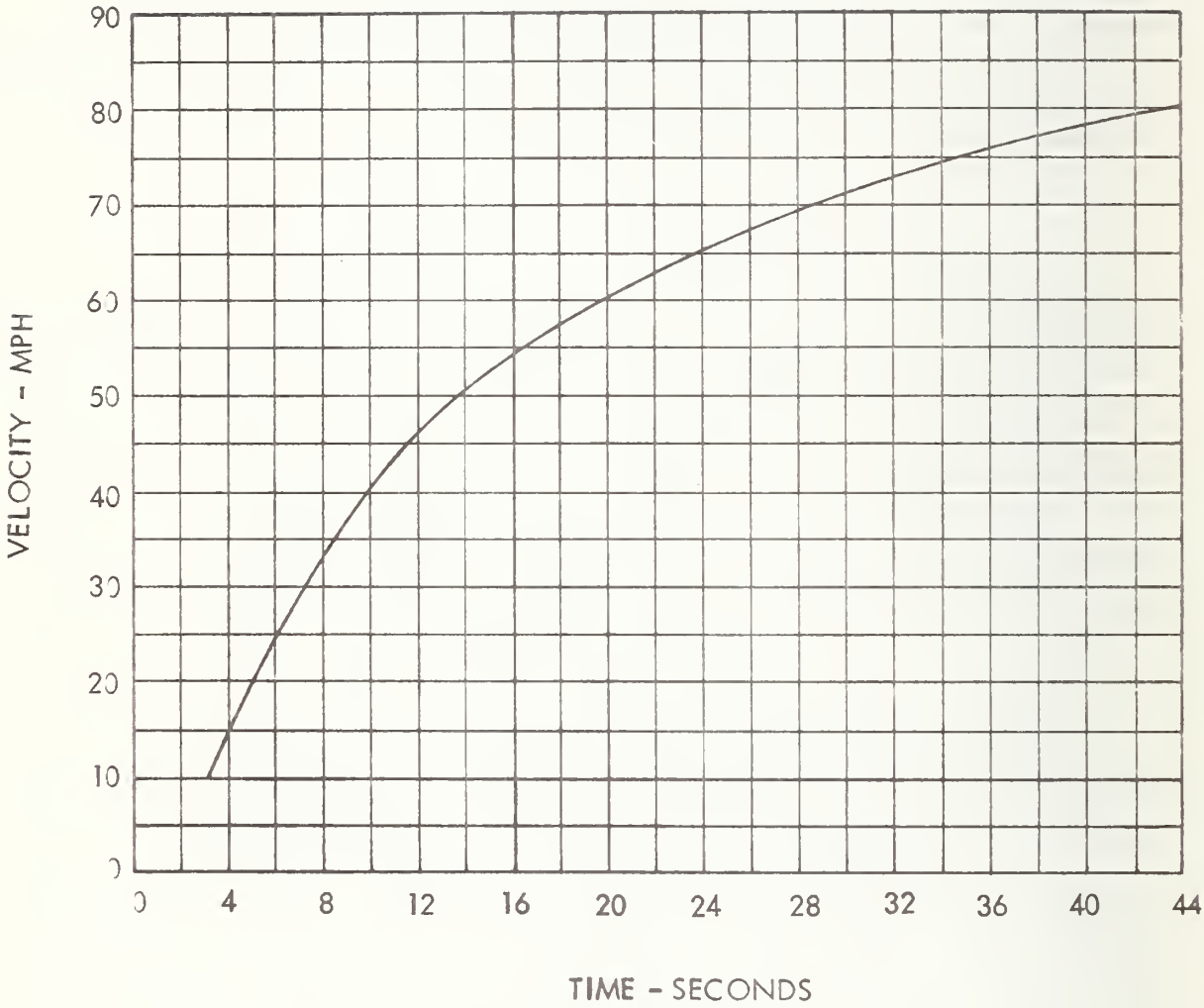


Figure 5-11. RSV Performance

future internal combustion engines will probably use a fuel injection or other similar systems for better control of exhaust emissions and for increased fuel economy, the problems of lateral force on vehicle performance will be eliminated.

Fuel Capacity

The range requirement has been retained since it is judged to be an acceptable value; the cruising speed has been changed to reflect the projected retention of the national 55 mph speed limit.

2.1.6 Ride Performance

The guideline specifications for ride performance are in terms of allowable bands of natural ride frequencies for the front and rear suspensions. The specification method leans more towards design rather than performance specifications. Further, the natural ride frequencies specified (0.9 to 1.1 cps for front and 1.2 to 1.4 cps for rear suspension) are the same as previously specified for larger size vehicles. In reality, most current small vehicles on the road have much stiffer springs for their weight category than do larger size vehicles because of the limited static suspension deflection space available.

Based on these considerations, the RSV specifications are presented in a completely revised format. An upper limit of rms acceleration values for the passenger compartment is specified at different frequencies. The specified limit for ride comfort is based on recommendation of the ISO [38] Committee for Human Engineering design criteria. The selected RSV limit is between the ISO limit of 8 hour exposure to maintain continued driver proficiency and the ISO limit for total comfort.

The limit for total comfort is not used directly because it is felt that it is too stringent for smaller cars and unrealistic for the 1985 time frame. This conclusion is based on the results of a test program

conducted by Stikeleather, et al, on motor vehicles, which found that compact cars did not perform as well as the larger cars. [39]

The specification limit requires ride comfort performance which is at a level above that exhibited by present production small cars, but, within the capability of 1985 RSV's because of the following two factors:

1. The RSV limit is not too far above present-day capabilities of smaller vehicles.

2. The state of the art advances reported recently such as a Hydragas suspension, and active suspension systems indicate that substantial improvement will be made within the next decade. [40,4

Ride comfort and handling performance of a vehicle impose opposing requirements on a vehicle's suspension system. This statement is more valid for a smaller car since the basic available static suspension deflection is limited. Hence, the selected ride comfort level is set at a level where substantial ride comfort will be achieved without sacrificing the vehicle's handling performance.

Careful attention is given to the frequency range of 4 to 8 Hz which is critical for human comfort, 5 to 7 Hz is the range wherein human viscera resonance sets in. The frequency range of 0.5 to 25 cps is the most important for actual ride amplitude. Above that range, the perception of vibrational motion diminishes and noise takes over; this is usually referred to as harshness of suspension. The RSV specifications cover both these ranges.

2.2 VISIBILITY SYSTEMS

2.2.1 Driver Visibility

Ideally, the driver should be provided with an unobstructed horizontal view of 360 degrees with adequate vertical angles around the vehicle including the ability to see the extreme outside edges of his vehicle. However, this

maximum field of view is unattainable without degrading the automobile safety structure or incurring added costs for vision improvement devices. Since it is very difficult to assess the deficiencies in viewing fields as accident causation factors, there is no quantified basis on which specifications for minimum acceptable direct and indirect fields of view can be established.

Where vehicle-related obstructions are cited as definite or probable [42] causes of accidents, the most often cited causes are ice, snow, frost or water condensation on the windows. No causal data citing interior or exterior car elements as driver obstructions contributing to an accident was found.

These considerations led to the retention of essentially all of the visibility systems specifications as presented in the guideline specifications. In retaining these specifications, consideration was given to the considerable effort given to the formulation of the basic requirements presented in notices of proposed rulemaking and these are judged to be viable requirements.

The differences between the RSV guideline specifications are in paragraph 2.2.1 and in the deletion of tradeoff studies and references to other contract developed data. In the cited paragraph, side mirrors with a cylindrical curvature are permissible. Tests by one investigator have [43] shown that convex (spherical) mirrors can be used safely by drivers and have the advantages of providing a considerably increased rear field of view compared to a planar mirror. It is anticipated that cylindrical convex mirrors will provide equally good viewing fields with less distortion. A further change in this paragraph exempts the right hand side mirror, if used, from being adjustable from the driver's seat. This requirement was considered to be too stringent.

The deletion of tradeoff studies and of the reference to other contract developed data were made because these are not directly related to RSV performance specifications and are more appropriate in a specification

for a design activity. The need for trade studies and other source data is recognized and these requirements should be addressed in follow-on phases in the form of work statements and in more detail by the potential investigators for those phases.

2.2.2 Lighting

An advanced three beam headlight system is specified to provide increased forward lighting with significantly better illumination than is had in present-day vehicles. The major difference between the current and [44] the specified systems are the addition of a mid-beam and an increase in the forward illumination distance of the high beam from 450 feet to 600 feet.

The low beam would be used conventionally when the vehicle is following another or when in heavy traffic. The mid-beam lamp should provide better vision on urban and rural streets and roads where higher speeds are allowed. In view of the relatively high projected frequency of on-road night collisions with fixed objects, the pattern shape of this beam should enhance the visibility of the right side of the road. With the sharp cut-off of the mid-beam pattern, any residual left hand glare should not affect on-coming traffic. The high beam is provided for high speed freeway travel.

The forward illumination distances specified were considered in terms of over-driving the beams. The table that follows presents the [45] California DMV test data on stopping distance as a function of speed based on average driver responses and the braking of average vehicles on dry surfaces and in daylight.

AVERAGE STOPPING DISTANCES

Speed (mph)	Thinking Distance (ft)	Braking Distance (ft)	Stopping Distance (Dry) (ft)	Stopping* Distance (Wet) (ft)
25	27	34.4	61.4	120
35	38	67	105	210
45	49	110	159	320
55	60	165	225	450
65	71	231	302	600

*Estimated

The stopping distance, which is the sum of the thinking and braking distances, is the distance the vehicle traveled while the driver sees a hazard situation, makes a braking decision and initiates braking and the car decelerates to a stop.

The cited thinking time is about 1.4 seconds. At night or under adverse weather conditions, this time would probably increase; therefore, the indicated stopping distances would increase.

For the specified forward illumination distances, the low beam would be adequate up to 55 mph on dry roads and 35 mph on wet roads; the mid-beam up to 65 mph and 40 mph on wet and dry roads respectively; and the high beam up to 60 mph on wet surfaces for the risk-taking driver. Therefore, the lighting specified for the RSV should allow the driver sufficient time to properly recognize road hazards and take proper action to avoid an accident with the appropriate selection of beams for his speed and road conditions.

The accident projection studies found that rear end collisions comprise about one-third of all projected vehicle to vehicle accidents (although severity levels in rear end accidents are not proportionate). A

number of directed studies indicated that improvements in the rear lighting system as a prime communication link with following vehicles could reduce the frequency of rear end involvements. On this basis, the requirements for rear lighting, in particular, were specified.

Rear signal lights which are separated and color coded for stop, [46 turn and presence functions are specified to minimize reaction time and driver errors. Redundancy is required for the critical functional lamps; lamp failure was shown to be a prime or contributory accident causation factor.

A decelerating signal lamp was specified based on tests which [48 found that rear end collisions can be reduced 60% with their use. In these tests, an amber colored light was center mounted on the rear of several hundred cars and their accident rate was compared with a control group of cars in a large urban area to evaluate rear end accident rates. The findings indicated the reported accident reduction potential.

2.3 DRIVER ENVIRONMENT SYSTEMS

2.3.1 Controls and Displays

The essentials of the guideline specifications have been retained with modifications. The modifications were made with the intent of: (1) broadening the requirements to encompass additional systems that may require monitoring; (2) removing any implied restrictions on the use of new systems; and (3) allowing the designer to select data from any appropriate source rather than specifically cited sources which indicate a preference.

The rationale for these requirements is based on sound engineering and design rather than accident causation data.

2.3.2 Warning Devices

The approach and rationale taken for these devices is essentially the same as that used for controls and displays. In specifying the warning requirements for the restraint system, the word "passive" was deleted since

the cost-benefit or cost-effectiveness of a passive restraint remains to be demonstrated. This does not imply that an RSV meeting crash energy management specifications will not incorporate a passive system.

2.3.3 Environment

The requirements for the interior environment have been made more definitive. In keeping with current practive, air conditioning is considered as an option. Further, air conditioning uses energy; it is estimated that approximately 1.5 mpg of fuel is used for air conditioning of a current intermediate class car on an urban driving cycle (similar to the federal driving cycle). It does not seem appropriate to specify air conditioning as a standard component in view of the projected fuel conservation programs. An acceptable comfortable level is attained in the current passenger car with air circulation for most weather conditions. If other design considerations preclude an acceptable performance with a ventilating system, then an air conditioning system will be required and its requirements are cited. It should be noted that the performance of production air conditioning units is not published and therefore, qualitative rather than quantitative comfort is specified.

The interior noise level has been specified based on measured data of subcompact cars. Interior noise levels for a representative set of small production cars for the 1974-1975 model years are as follows:

	Sound Level, dBA @			
Model	Idle	30 mph	50 mph	70 mph
Chevolet Nova (3-speed automatic)	52	62	67	72
Mercedes 280S	N.A.	63	68	73
Fiat 124	56	68	72	77
Chev. Monza, V-8	55	60	67	74
Mustang II, V-8	60	61	68	73
Mazda 808 Coupe	N.A.	66	70	76
AM Pacer	55	62	70	76
Toyota Corolla	51	67	72	81
AVERAGE	55	64	69	75

There is a considerable spread in the noise levels experienced in these cars. The Chevrolet Nova (incorporated a 3-speed automatic transmission) exhibited the lowest reading at the speed step measured. Since this model represents the best noise performance in current small production cars, its noise levels were selected for the RSV specifications. The consideration in selecting the lowest value rather than an average or those associated with the smaller cars is that noise influences driver conditions (comfort, fatigue, distraction, etc.) and minimum noise is commensurate with a safety vehicle.

Vibration levels have been treated previously under Ride Performance.

2.3.4 Emergency Equipment

The specified equipment is the minimum required for the emergency conditions experienced with the vehicle breakdown or accidents. Since road repair is a hazardous operation and other than simple repairs are not attempted by the average driver, the spare V-belts and tool kit have been deleted as requirements.

2.4 CRASH ENERGY MANAGEMENT

The structural and occupant protection performance requirements recommended in Section 2.4 of the specifications represent what is believed to be the best performance achievable within the current state of the art considering weight and cost effectiveness, design practicality and producibility. The impact speed design requirements as specified are highly dependent on benefit/cost analyses, reported herein (in these analysis, weight is taken as a measure of cost). These are, in turn, strongly dependent on preliminary vehicle design data. Consequently, it is anticipated that adjustments to the impact design requirements (presented in specification Section 2.4) will be required in Phase II as detailed design data becomes available.

Furthermore, recent press releases by General Motors and Ford indicate that in the near future, a more rapid decrease in vehicle sizes than that projected earlier in this Phase I study is to be expected. If this rapid trend to lower vehicle weights materializes, a much more favorable car mix will result in the mid-80 time frame and the RSV/5000 lb car encounter reflected in the performance specification will be conservative. A new evaluation of the mid-80 car mix is indicated early in Phase II as the trend becomes more firmly established, and appropriate changes made to the specification (with government approval) at that time.

The following discussion serves as supporting rationale for the Phase I crash energy management performance specifications. The rationale is presented in terms of system level considerations as governed by the projected accident modes, estimated safety payoff potentials, and aggressivity compatibility in the projected vehicle mix. This rationale is therefore applicable to several of the individual specifications and in particular to specification Section 2.4.1, Structural Systems.

System Level Considerations

The basis for the crashworthy performance specifications are the accident projections and results from the societal cost studies conducted during Phase I program definition. These are documented in Section 3.3, Societal Costs and Benefits, Volume II. In those studies, it was determined that car-car accidents represent, by far, the single greatest source of fatalities and injuries projected for the 1985 time frame. The various accident modes investigated and their respective ranking and maximum payoff (in terms of societal costs) determined in the program definition studies are summarized in Table 5-5.

Table 5-5

Summary of Societal Cost Analysis Results

Accident Mode	Maximum Payoff Potential* $ Billions	Ranking
Car-car	17.0	I
Car-fixed object	3.8	II
Car-pedestrian	2.4	III
Car-pedalcycle	.7	IV
Rollover	.4	V
Car-motorcycle	.2	VI

*Based on impact speeds within the current state of the art in vehicle crashworthiness and the assumption that 100% of casualties within the speed range are saved.

The results in Table 5-5 indicate that car-car accidents far outrank the remaining accident modes in terms of societal cost (by at least 4:1) and consequently should be given primary consideration in the RSV crashworthiness performance specifications.

Since the car-car accident mode plays such a vital role in defining the crashworthiness requirements for the RSV, it was deemed necessary to place emphasis on the problem of vehicle-vehicle compatibility (i.e., vehicle aggressiveness). Two aspects of this problem were addressed: (1) the RSV as an aggressor against smaller vehicles, and (2) the larger vehicle as the aggressor against the smaller RSV. The approach taken in this study was to consider the 3000 pound RSV as an optimum design "target" for the 1985 time frame, and to enforce design constraints on all vehicle sizes so that car-car compatibility is achieved with minimum risk and design penalties (in terms of weight, design complexity, etc.) imposed on the "target" RSV. This approach results in progressively stiffer penalties for vehicles weighing significantly more or less than the target vehicle as illustrated in Figure 5-12. The penalty imposed on the smaller vehicles would be reflected primarily as a higher driving risk with a lower "safe" impacting speed. The penalty imposed on the heavier vehicles would be reflected in the design complexity (hence cost) associated with the crash energy management systems to accommodate the added crush required to limit the accelerations of the "target" vehicle (RSV). For example, this penalty could be reflected in a requirement to deflect the engine during impact, or to relocate the engine so that all the space between the bumper and firewall could be used for crush.

Obviously, the most desirable situation is one in which the system penalties are minimized, uniformly distributed and a favorable crashworthiness level is maintained for all vehicles. Ideally, this situation will only occur when all vehicles within the population are of the same size, weight, and have similar structural characteristics and all are designed to a satisfactory level of crashworthiness. The fact that the real environment is not ideal, but is comprised of a heterogeneous mixture of vehicle sizes and weights with varying structural characteristics, suggests that an imbalance will exist between crashworthiness and associated penalties

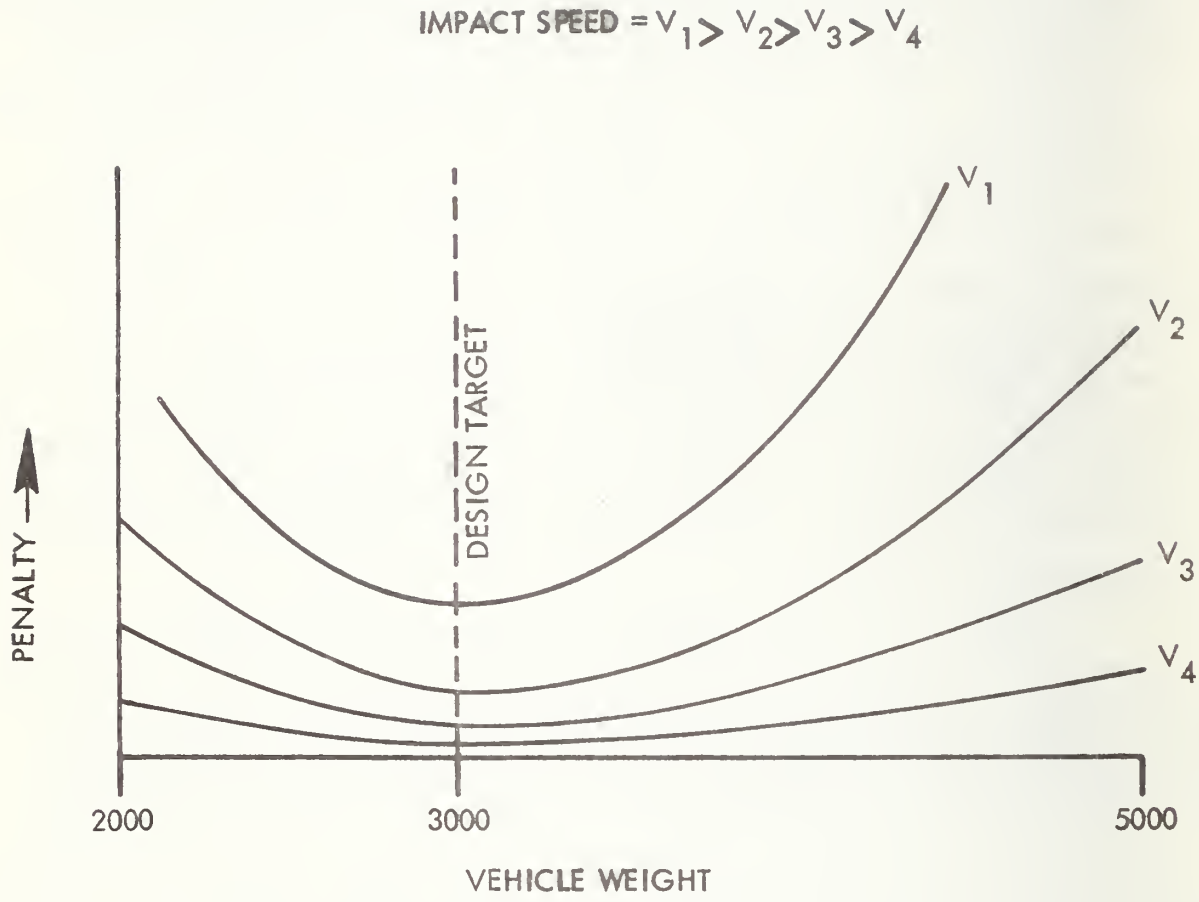


Figure 5-12 Design Philosophy, Vehicle - Vehicle Encounter

for various vehicle sizes. The most that can be hoped for in the real environment is that a major segment of the total vehicle population will receive optimum impact protection (associated with minimum penalties) at the expense of the remaining population. The vehicle mix trend resulting from the usage projections indicates a trend towards smaller and lighter vehicles into the mid-80's. It is envisioned that the vehicle mix beyond the mid-80's will result in a major segment of the vehicle population being similar to the RSV in size, weight and structural characteristics. With this in mind, the proposed conceptual approach illustrated in Figure 5-12 appears reasonable.

Two studies were conducted to evaluate the problem of car-car compatibility and to obtain a measure of the system penalties associated with the RSV structural optimization methodology previously described. The first study was conducted to determine the extent to which the small vehicles (under 2800 pounds) comprising the vehicle population would be penalized in favor of the heavier RSV (2800-3000 pounds)*. The second study investigated the compatibility requirements of the larger vehicle (over 3000 pounds) and the associated design penalties.

RSV - Small Car Compatibility

The first study, dealing with RSV aggressivity against smaller vehicles, addressed the problem by determining the probability that an RSV - small car encounter will occur in the projected 1985 environment. If the probability of an RSV - small car encounter is sufficiently low, it would be reasonable to assume (at least from a system penalty standpoint) that penalizing the small car in favor of the larger RSV (which comprises a larger segment of the total vehicle population) will be acceptable.

This study consisted of the following elements:

- Determine the current curb weight distribution of subcompacts and compute the mean curb weight value.

*This weight range was arbitrarily selected as a first estimate of the RSV curb weight.

- Project the mean curb weight values for subcompact, compact, intermediate, specialty and standard automobiles to the 1985 time frame.
- Calculate the 1985 automobile population in terms of lumped weight classes of under 3000 lb, 3000-4000 lb, and 4000-5000 lb.
- Determine the probabilities of the RSV-type vehicle (under 3000 lb) being involved in an accident with the various lumped weight classes.
- Determine the probabilities of the RSV-type vehicle (2800-3000 lb) being involved in an accident with lighter vehicles (under 2800 lb).

With the use of available curb weight trend plots, projections [49] for 1985 were determined as shown in Figure 5-13. From the 1973 sales and curb weight data, the subcompact curb weight distributions were calculated and graphed in Figure 5-14. The mean 1973 subcompact curb [50] weight value was found to be 2350 lbs. In Figure 5-13, the projected mean curb weight for 1985 subcompacts is shown to be 3000 lb. The simplifying assumption was made that the subcompact curb weight distribution in 1985 will be identical to the 1973 data with the exception that the 1985 distribution is displaced such that its mean is 3000 lbs. Thus, Figure 5-14 has two weight scales, one for reading 1973 values and the other displaced scale for reading estimated 1985 values.

As noted previously, there are indications that the prior trend through 1974 to steadily increasing weights will be reversed starting in 1975 and probably continuing through 1980. Based on the cited [51, references, General Motors intends to reduce the weight of intermediate 52] and standard models that currently average 4,500 pounds by 500 to 1,100 pounds. The subcompact and compact models will probably undergo

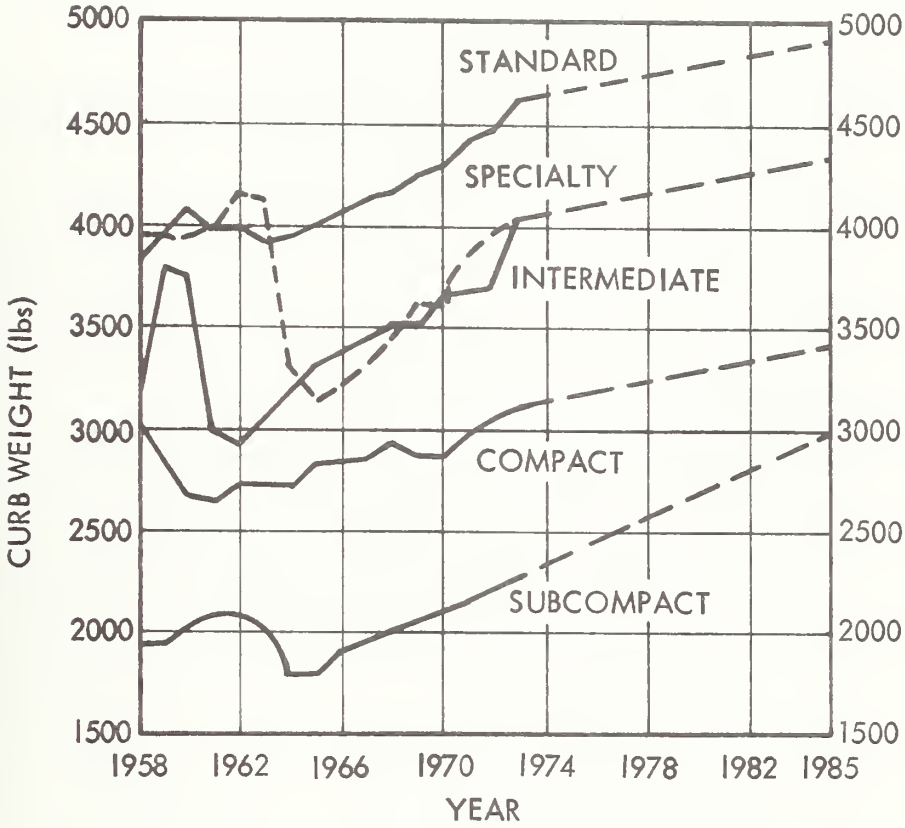


Figure 5-13 Curb Weight Trends Market Class

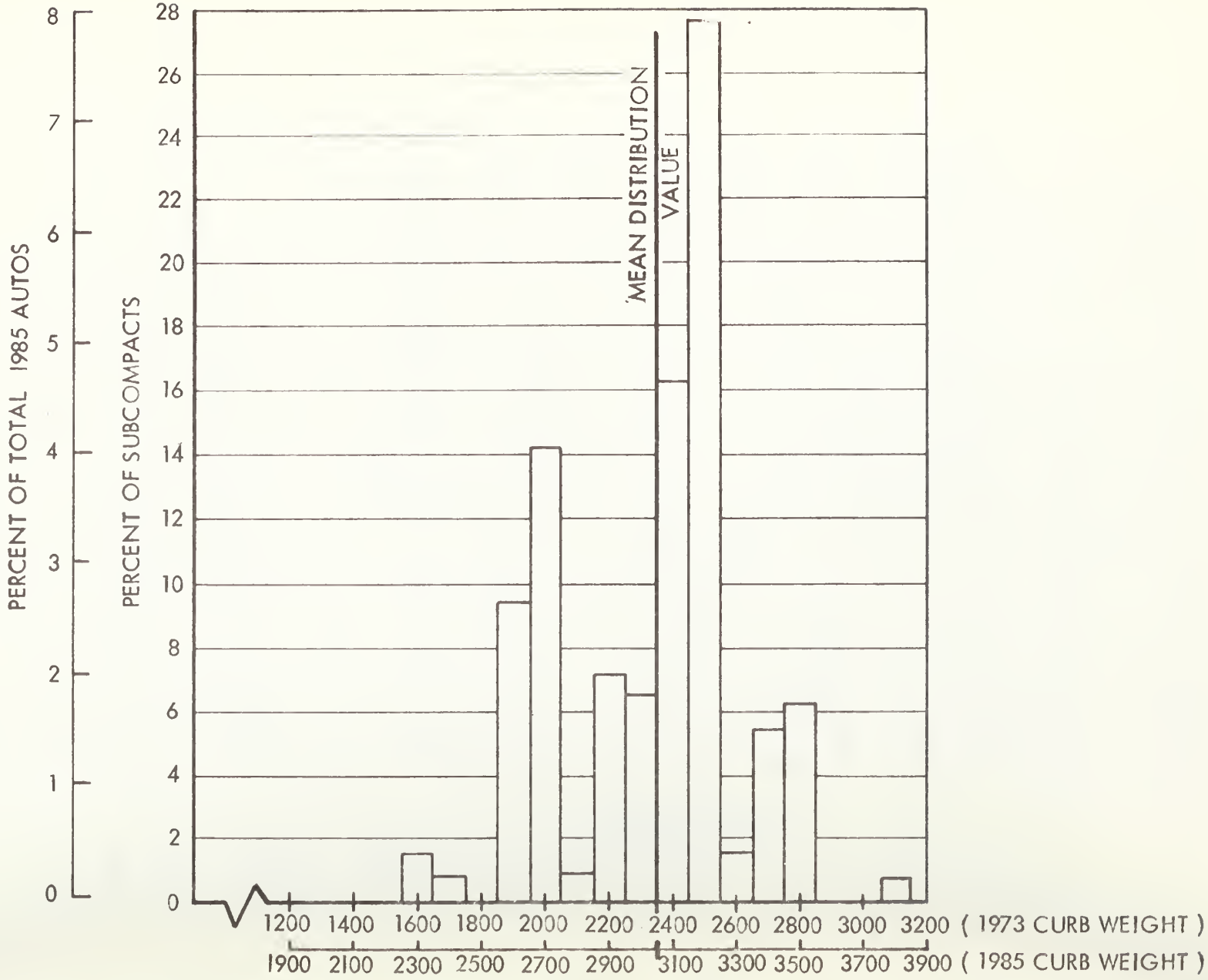


Figure 5-1 Distribution of Subcompacts by Curb weight

little or no reductions. The reported time frame for this reduction program is to run through to the 1978 model year. The intentions of Ford and Chrysler were not reported specifically, however, it is anticipated that competitive pressures will involve them in a similar program which may extend up to 1980. At this time, the intentions of the U.S. automotive industry as a whole regarding the extent and timing of the introduction of lighter vehicles are neither clear nor firm enough to alter the subject projections of vehicle weight mixes with any degree of confidence. If the announced intentions materialize, the weight differentials between cars in the RSV class and cars in the intermediate and standard classes will be reduced thereby reducing the system penalties associated with achieving aggressivity compatibility in the projected vehicle mix. It is anticipated that within the early stages of Phase II of this program, the weight reduction plans of the industry will have matured enough to permit an updating of the projections and specifications developed in Phase I.

From the usage projections, the 1985 automobile population of 123.6 million may be described by the distribution given in Table 5-6. Subsequently, instead of dealing with market class (e.g., compact, standard, etc.), the analysis categorizes automobiles by weight class. The 1985 weight classes are identified by the various market classes as follows:

- Subcompacts — under 3000 lb
- Compacts — 3000-4000 lb
- Intermediates, Specialties and Standards — 4000-5000 lb

In determining the RSV accident involvmeent probabilities, the simplifying assumption is made that the probability distribution of accident involvement between automobiles of various weight classes is directly proportional to the population distribution by weight. The probabilities of vehicles weighing less than 3000 lb being involved with each of the three primary vehicle weight classes are given in Table 5-7.

Table 5-6. 1985 Automobile Population by Weight and Age Distribution

		VEHICLE WEIGHT (LBS)		
		< 3000	3000 - 4000	4000 - 5000
VEHICLE AGE (YEARS)	UNDER 3	.042	.207	.083
	3 TO 5	.044	.212	.085
	6 TO 8	.025	.132	.057
	OVER 8	.014	.043	.056
	TOTALS	.125	.594	.281

Table 5-7

Probabilities of Vehicles Weighing Less than 3000 lb Being Involved With Vehicles of Various Weight Classes

Weight Group	Probability
Under 3000 lb	.016
3000-4000 lb	.149
4000-5000 lb	.070

It is conservatively assumed that all vehicles weighing between 2800 and 3000 lb will be RSV-like in nature. The probabilities of the RSV being involved with vehicles equal to or less than its weight are given in Table 5-8. Note that of all the probable accidents that will occur, only 0.7 percent will involve an RSV-class vehicle (2800-3000 lb) with vehicles equal to or less than its weight.

Table 5-8

Probabilities of RSV-Class Vehicles Being Involved in Accidents With Vehicles Equal to or Less Than its Weight

Weight Group	Probability	Cumulative Probability
2200	.0002	.0002
2300	.0001	.0003
2400	--	.0003
2500	.0013	.0016
2600	.0019	.0035
2700	.0026	.0061
2800 to 3000	.0009	.0070

In summary, this investigation shows that due to the very low accident encounter probability, it is unlikely that the RSV will play a significant role (as visualized from the system standpoint) as an aggressor against the lighter vehicles. The principal problem of aggressivity will exist when larger vehicles strike the smaller, RSV-type vehicles (see Table 5-7).

RSV - Large Vehicle Compatibility

The second study addressed the problem of vehicle compatibility with a large (over 3000 pounds) vehicle impacting the RSV. Here, the problem was to determine the characteristics required of the large vehicles to accommodate the crashworthy requirements of the RSV, and from this, evaluate the system penalties involved. However, before an evaluation could be made of the desired large car characteristics, acceptable crash performance criteria for the RSV were required. From previous ESV work, it was determined that the following crash performance characteristics were reasonable initial assumptions for the RSV.

Impact Direction	Occupant Compartment Maximum Intrusion* (inches)	Occupant Compartment Maximum Acceleration (g's)	Maximum Impact Load (kips)
Front	3.0	40.0	120.0
Side	3.0	20.0	60.0
Rear	3.0	40.0	120.0

*Additional intrusion is permissible with sufficient technical justification.

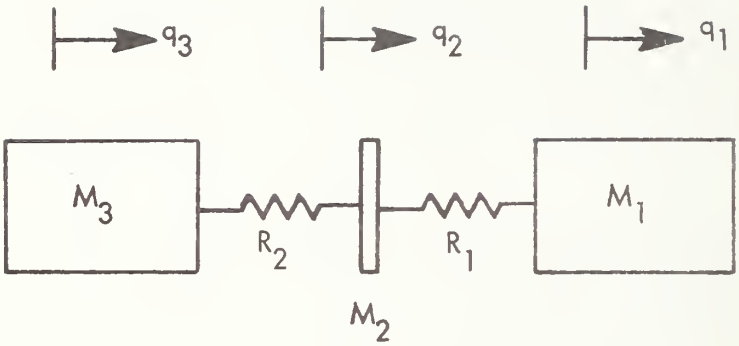
The assumed acceleration limits represent the upper limits of vehicle acceleration which can be accommodated by an effective restraint.

To insure the compatibility between the RSV and other larger vehicles operating in the same traffic environment, it is necessary to develop and enforce a common structural performance standard for all vehicle sizes. To

develop an idealized version of such a standard, the following analytical approach was taken. The computer model, shown schematically in Figure 5-15, was used to simulate the dynamic interaction resulting when two idealized vehicles collide. The model shown is one dimensional consisting of three degrees of freedom, one degree of freedom assigned to each of the three mass elements. The mass elements are interconnected by two nonlinear spring elements, R_1 and R_2, representing the idealized dynamic crush characteristics of the two vehicles. For this study, it was not necessary to simulate the dynamic impedance associated with the bumper mass, M_2, since this impedance was included in the crush characteristics of the two vehicles, R_1 and R_2. M_2 was arbitrarily assigned a very small mass value to make it responsive and was used merely to indicate the two crush zones (impacted/impacting vehicle).

The characterization study was conducted in two phases. The first phase was concerned with the compatibility of an impacting vehicle's front structure with an RSV side structure. For this phase, the idealized side crush characteristics were represented by a linearly increased curve reaching a plateau of 60 kips (20 g limit) in four inches of crush, as shown in Figure 5-16. The idealized front structure characteristics of the impacting vehicle are represented by the bottom curve of Figure 5-16. This curve consists of an initial "flat" zone representing a 5 mph no-damage stroke with an acceleration limit of 5 g's, followed by a linearly increasing curve defined by a slope K_1, to a peak value of 60 kips (20 g limit for RSV side structure). The parameter K_1 was varied to determine the optimum structural performance envelopes for the various vehicle weights of interest.

The second phase of this study was concerned with the characterization of the front structure for front-front collisions. In this phase, the idealized structural characteristics, shown in Figure 5-17, were used. It is to be noted that the initial portion of the curves, represented by the parameter K_1, were defined from the results of the first phase. The parameter K_2 was varied to determine the optimum structural characteristics for the various vehicle weights of interest.



M_1 = IMPACTED VEHICLE MASS

M_2 = FICTICIOUS MASS ELEMENT TO DENOTE CRUSH DISTRIBUTION

M_3 = IMPACTING VEHICLE MASS

R_1 = STRUCTURAL RESISTANCE OF IMPACTED VEHICLE

R_2 = STRUCTURAL RESISTANCE OF IMPACTING VEHICLE

Figure 5-15 Computer Model for Vehicle - Vehicle Compatibility Study

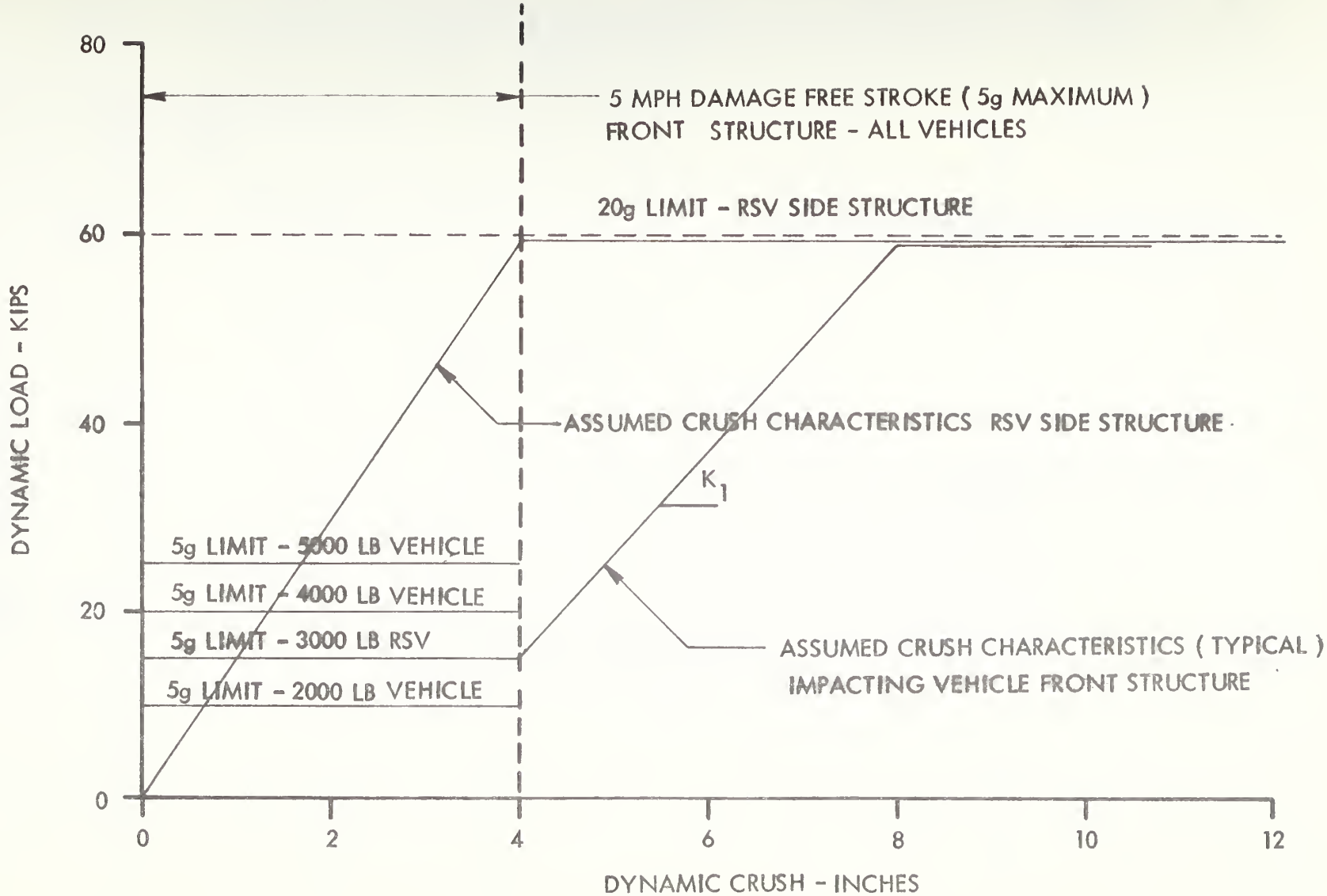


Figure 5-16 Idealized Crush Characteristics for Front - Front Characterization Study

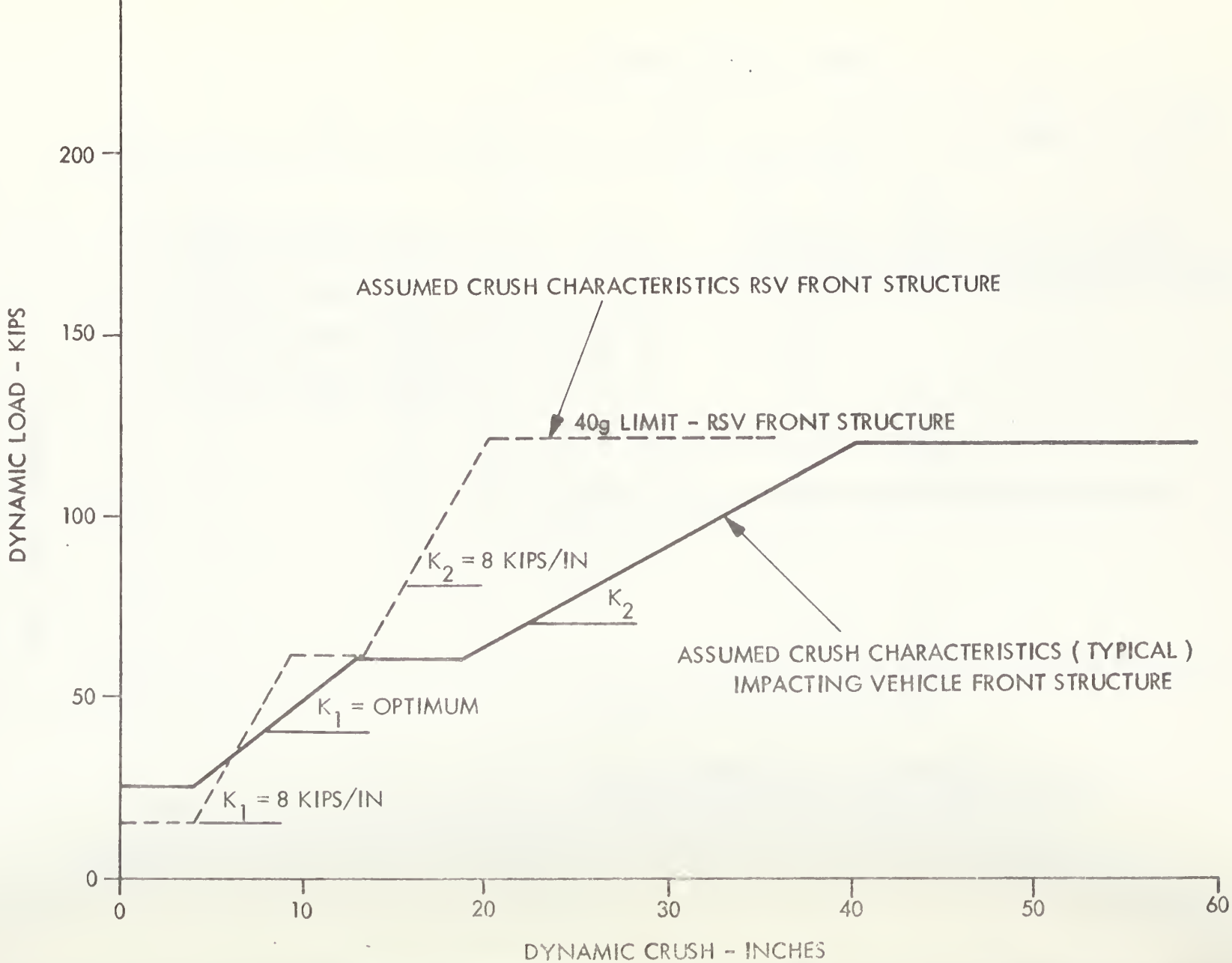


Figure 5-17 Idealized Crush Characteristics for Front - Front Characterization Study

The impact conditions simulated in the characterization study represent what were believed to be upper and lower bound for vehicle crashworthiness designs. The upper bounds represented the limit of the current state of the art in vehicle crashworthiness design. The lower bounds represented the lower impact speed limit that would provide a minimum acceptable safety benefit to society as a whole. The upper and lower bounds assumed for this study were:

Impact Direction	Upper Bound Impact Speed	Lower Bound Impact Speed
Front	100 mph	80, 90 & 100 mph
Side	40 mph	30 mph
Rear*	40 mph	40 mph

*For this impact direction, higher impact speeds are within the current state of the art; however, the societal cost studies do not indicate a need for designing beyond 40 mph.

Of the three impact configurations listed, two stand out as being critical for design, the frontal and side impacts. Rear impacts are significantly less critical owing to the moderate design impact speed (40 mph), favorable acceleration limits (40 g's), and the available crush space (generally greater than the crush space available for side impacts).

The analytical results of the first phase of the characterization study are summarized in Figure 5-18. In this figure, the dynamic crush of the RSV side structure resulting from a front-side collision is shown as a function of the parameter K_1, and the mass of the impacting vehicle. Also shown is the limiting side structure crush (9.8 inches) required to maintain a maximum passenger compartment intrusion of 3 inches. This limiting value was obtained from a study by Hofferberth, the results of which are summarized in Figure 5-19. [53]

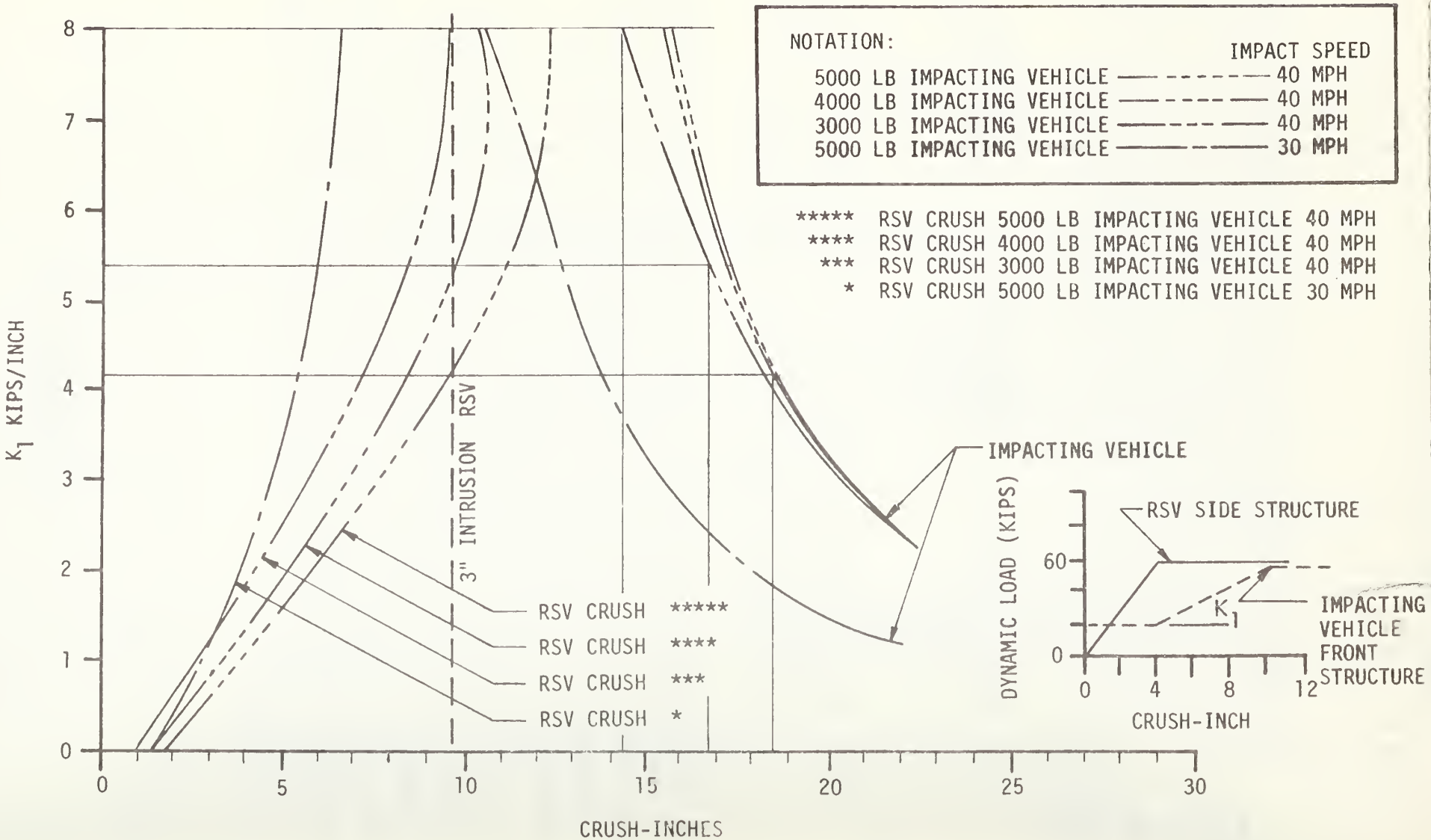


Figure 5-18 Front Structures Characterization Front-Side Collision

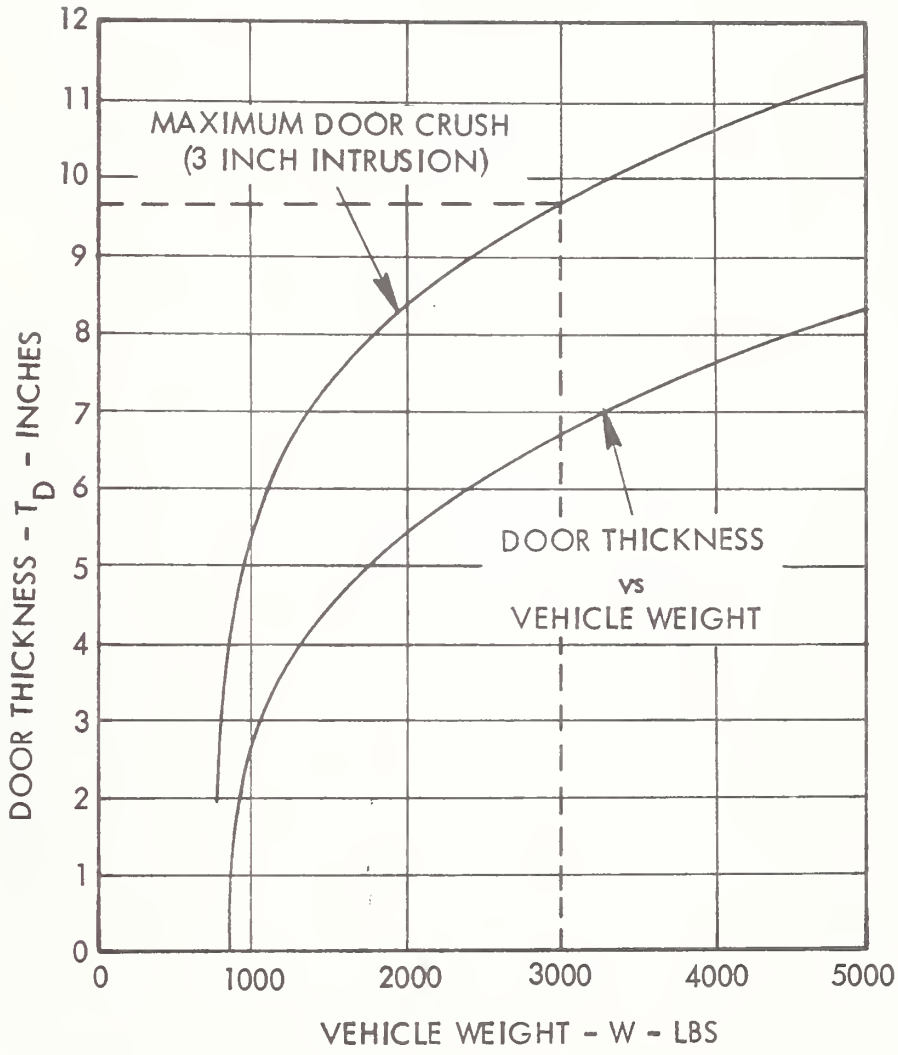


Figure 5-19 Side Door Thickness as a Function of Weight

The optimum values obtained from Figure 5-18 for the parameter K_1, required to insure vehicle to vehicle compatibility for front-side collisions and the resulting crush distributions between the impacted and impacting vehicles for both the upper and lower bound impact conditions are shown in Table 5-9.

Table 5-9

Results of Front-Side Impact Characterization Study

Impacting Vehicle Weight, lbs	Parameter K_1 (Optimum Value), kips/in	RSV Side Crush, in	Impacting Vehicle Front Crush, in	Impact Speed mph
5000	4.2	9.8	18.5	40
4000	5.4	9.8	16.9	40
3000	8.0	9.8	14.3	40
5000	35.0	7.53	8.83	30

These results show that for the 40 mph front-side impact case, the parameter K_1 is critical and must be limited as indicated in Table 5-9. However, for the 30 mph case, it appears that the energy to be dissipated is sufficiently low so that K_1 can be made arbitrarily high, thus allowing a more efficient front end crush stroke for the larger vehicles.

The results of the second phase of this characterization study are summarized in Figures 5-20 and 5-22, where the dynamic crush of both the RSV and the opposing vehicle are shown as a function of the parameter K_2 and the mass of the opposing vehicle. Here, "limit" crush is used to denote the RSV crush associated with impacting another RSV (or against a rigid barrier at approximately half the speed). The assumption was made that the total front end design crush of an RSV for impacts against another RSV or a fixed object is not exceeded when impacted by a larger vehicle. Figure 5-20 shows the results for the upper bound impact speed cases (100 mph front-front; 40 mph front-side). The results indicate

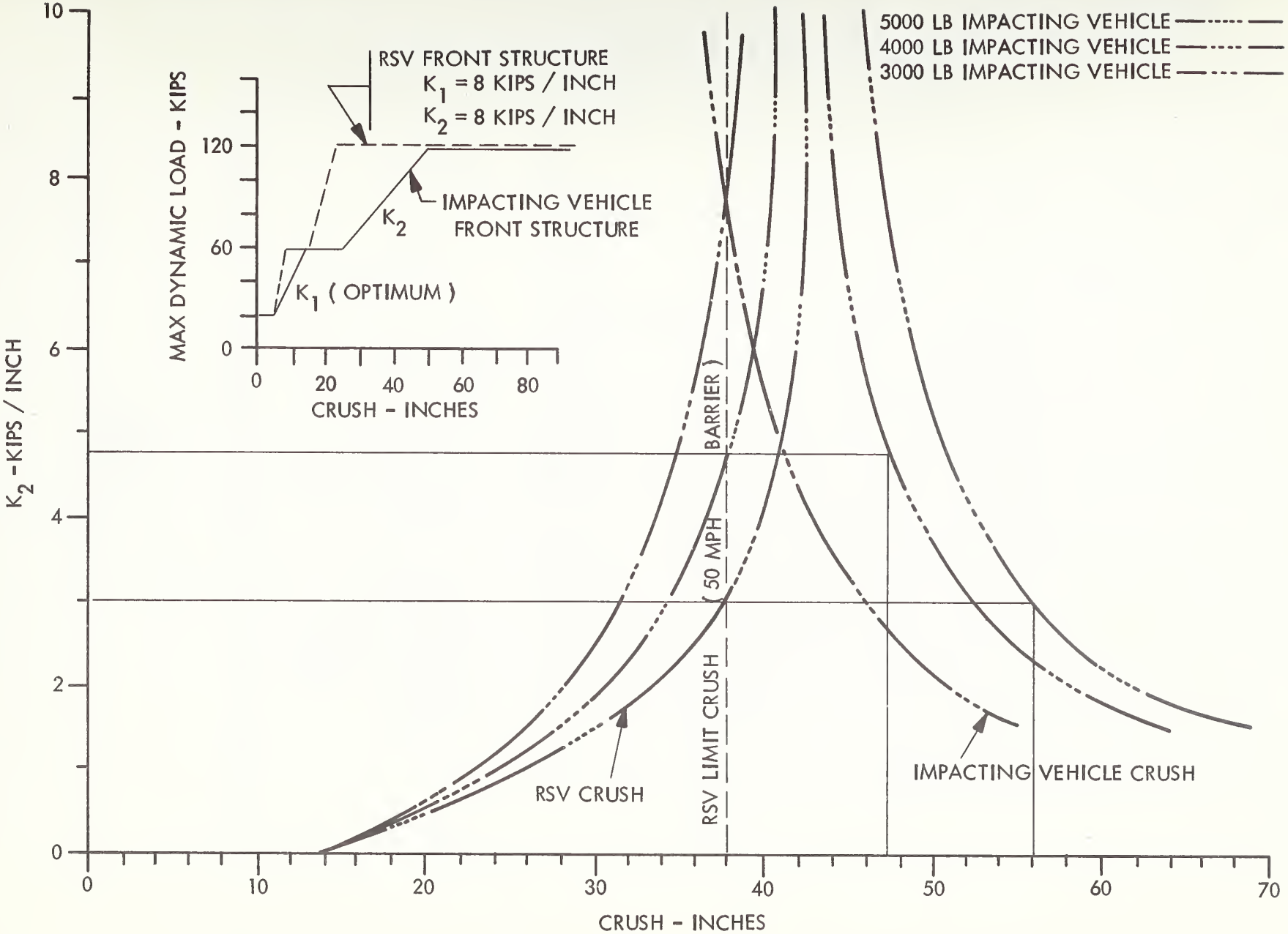


Figure 5-20 Front Structure Characterization Front-Front Collisions, 100 MPH Closing Speed; Front - Side Collision 40 MPH

that for this impact design speed, a severe penalty is required for the large vehicle in order to accommodate the crashworthy requirements of the RSV. For example, a 5000 lb vehicle requires a K_1 value of 4.3 kips/in and a K_2 value of 3.0 kips/in (see Figures 5-18 and 5-20 respectively) and results in a total front end crush of 56 inches for the upper bound impact case. A study by Hofferberth shows that for a 5000 lb vehicle, the total [53] crush distance between the bumper and firewall is approximately 65 inches (see Figure 5-21). Allowing for three inches of intrusion and a stroke efficiency of 75% gives a maximum available crush of 51 inches. Obviously, with the 56 inch crush requirement, this impact configuration can only be accommodated by compromising the crashworthiness of one or both vehicles by allowing greater intrusion into the occupant compartment or increasing the occupant compartment acceleration limit. Furthermore, it should be noted that, because of the large crush requirements of the larger vehicles, designing to this impact speed level may require all larger vehicles to have a mid or rear engine configuration since it will be virtually impossible to deflect a large engine from the front compartment during impact without being overly aggressive to the RSV. This is a rather severe design penalty. Table 5-10 summarizes the findings for this case.

Table 5-10

Results of Front-Front Impact Characterization Study
(100 mph Front-Front Impact; 40 mph Front-Side Impact)

Impacting Vehicle Weight lbs	Parameter K_2 (Optimum Value) kips/in	RSV Front End Crush in	Impacting Vehicle Front End Crush in	Available * Crush Impacting Car in
5000	3.0	38.0	56.0	51.0
4000	4.8	38.0	47.0	46.5
3000	8.0	38.0	38.0	42.0

*A stroke efficiency of .75 assumed, maximum stroke determined from Figure 5-21.

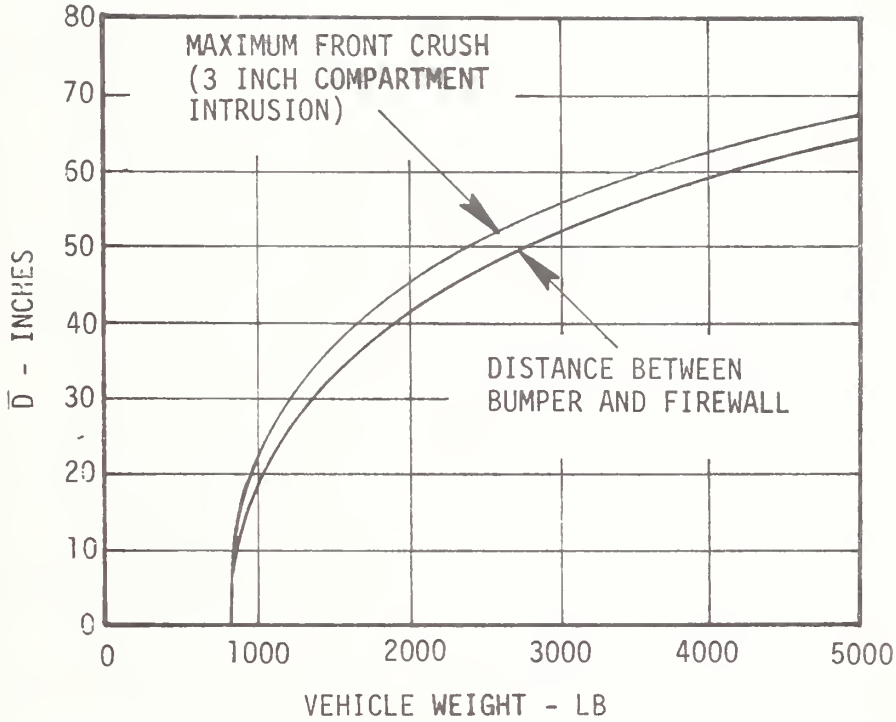


Figure 5-21 Distance Between Bumper and Firewall as a Function of Weight

The lower bound impact design speeds were evaluated for system penalties using the same approach, starting first with a 30 mph front-side impact configuration. Figure 5-22 summarizes the results obtained. The case considered is a front-front collision mode involving an RSV and an opposing 5000 pound vehicle (with front end crush characteristics that are compatible with an RSV side structure for a 30 mph impact speed, see Table 5-9). Figure 5-22 shows the crush of the RSV and 5000 pound vehicle front structures as a function of the parameter K_2 and impact speed. Also shown are the RSV front end limit crush values corresponding to barrier impact speeds of 40, 45 and 50 mph. As previously noted, it was assumed that these limit crush values are not to be exceeded for RSV - large car impacts at the corresponding relative impact speeds (i.e., 80, 90 and 100 mph respectively). The results of this case are summarized in Table 5-11.

Table 5-11

Results of Front-Front Impact Characterization Study (Lower Bound Impact Speeds)

Impacting Vehicle Weight lbs	Relative Impact Speed	K_2 kips/in	RSV Front End Crush in	Large Car Crush in	Available * Stroke (Large Car)
5000	100	2.8	32.5	47.5	51.0
5000	90	3.0	27.6	41.0	51.0
5000	80	3.2	23.5	35.0	51.0

*A stroke efficiency of .75 assumed, maximum stroke determined from Figure 5-21.

Obviously, this case is much less severe than the previous case since here even at the 100 mph impact speed range, ample stroke is available (see Table 5-11). However, it should be noted that an engine deflection scheme (or engine relocation) is still required for the full impact speed

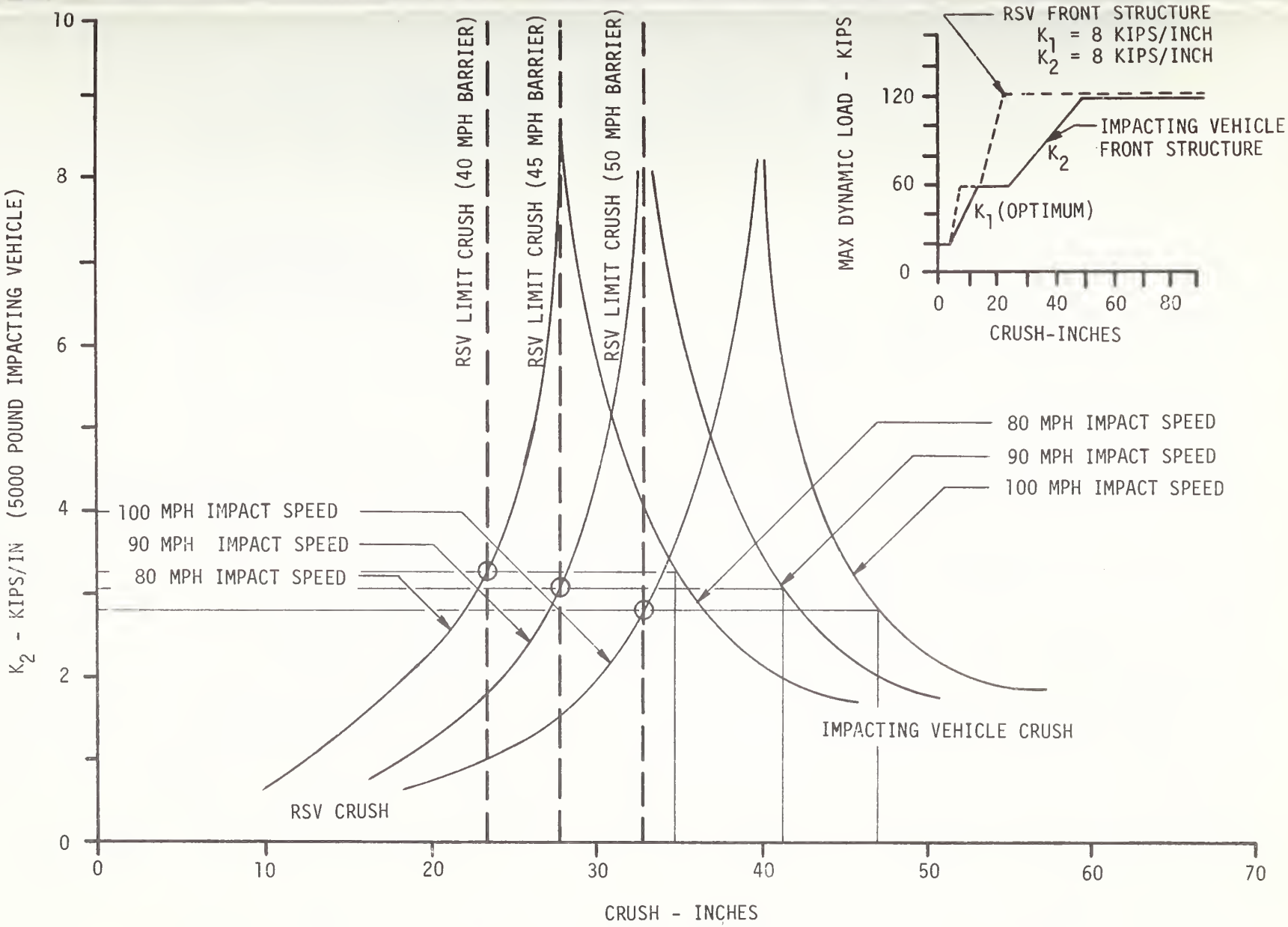


Figure 5-22 Front Structure Characterization, Front-Front Impact Configuration at Various Impact Speeds

range considered. For example, assuming that an engine block has a length of approximately 22 inches, it is apparent from Table 5-11 that an engine mounted adjacent to the firewall would have to stroke approximately 18 inches, 12 inches and 6 inches for respective relative impact speeds of 100, 90 and 80 mph. From past experience, the engine displacement requirement of 18 inches does not appear feasible. For this higher impact speed, engine relocation appears to be the only solution (short of reducing the crashworthiness of one or both vehicles). A more reasonable design limit is the 12 inch requirement corresponding to an impact design requirement of 30 mph front-side and 90 mph front-front.

It is again noted that this analysis is somewhat conservative based on anticipated trends that were not reflected in the projected mid-80 usage environment. If a trend to lowered weights is firmly established, new projections for the 1985 time frame will probably reveal very few 5000 lb vehicles, and a more reasonable "large" car target will probably be around 4000 pounds. This will undoubtedly reduce the system penalties associated with RSV - large car impacts as described in the preceding paragraphs.

The analytical results for both phases of the above characterization study are combined to form the sets of curves shown in Figures 5-23 and 5-24. Figure 5-23 represents the load deflection characteristics required for the full range of vehicle sizes to assure compatibility with the RSV. For this set of curves, the upper bound impact speeds (100 mph front-front; 40 mph front-side) are assumed. Figure 5-24 shows the required load deflection characteristics of a 5000 lb vehicle for compatibility with the RSV at the lower bound impact speeds (80, 90, 100 mph front-front; 30 mph front-side). Also superimposed on Figure 5-24 are the load deflection characteristics for a 5000 lb vehicle designed to the upper bound impact

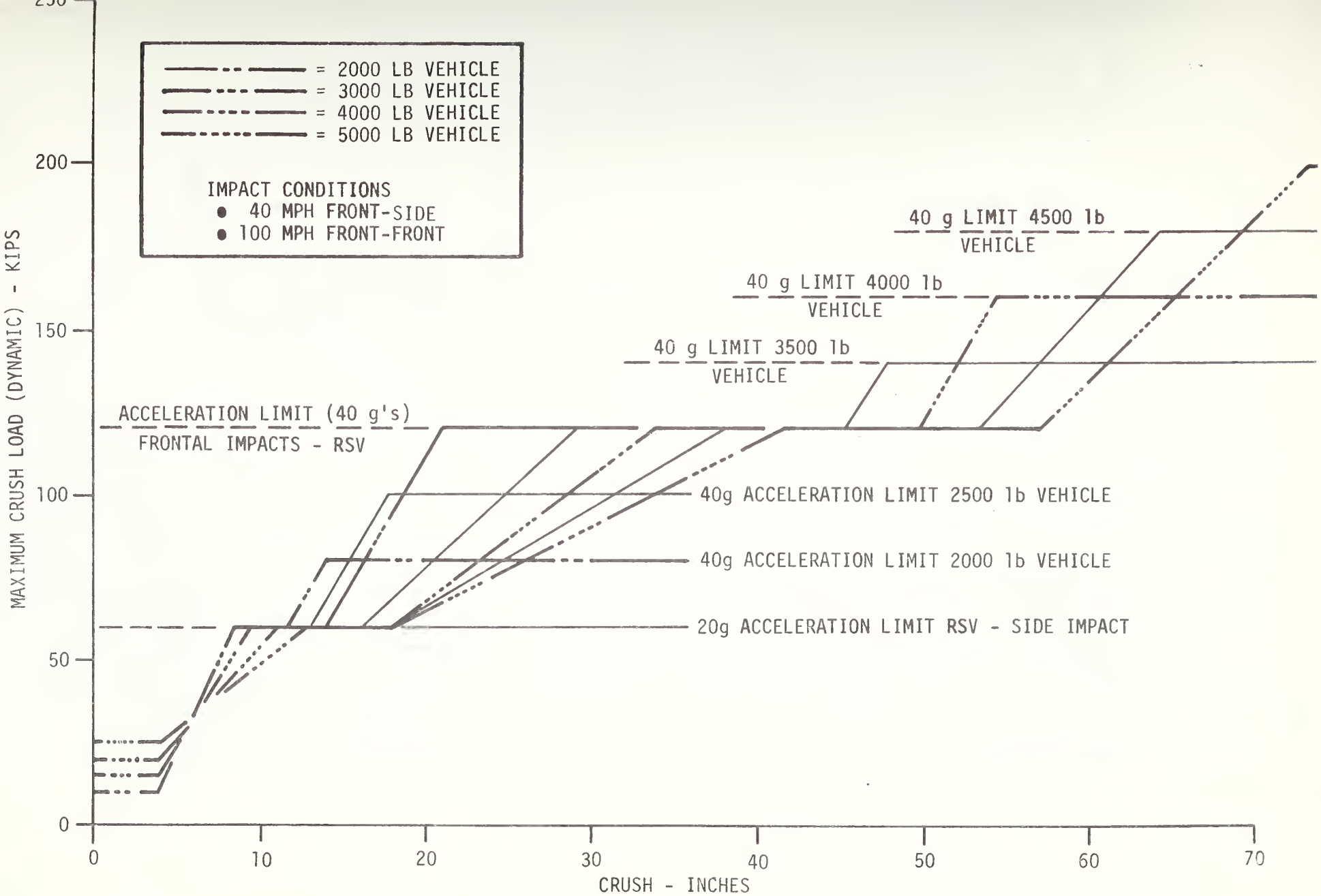


Figure 5-23. Front End Stiffness Characteristics for Vehicle-Vehicle Compatibility in 100 mph Front-Front Impacts (Front End Optimized for 40 mph Front-Side Collisions)

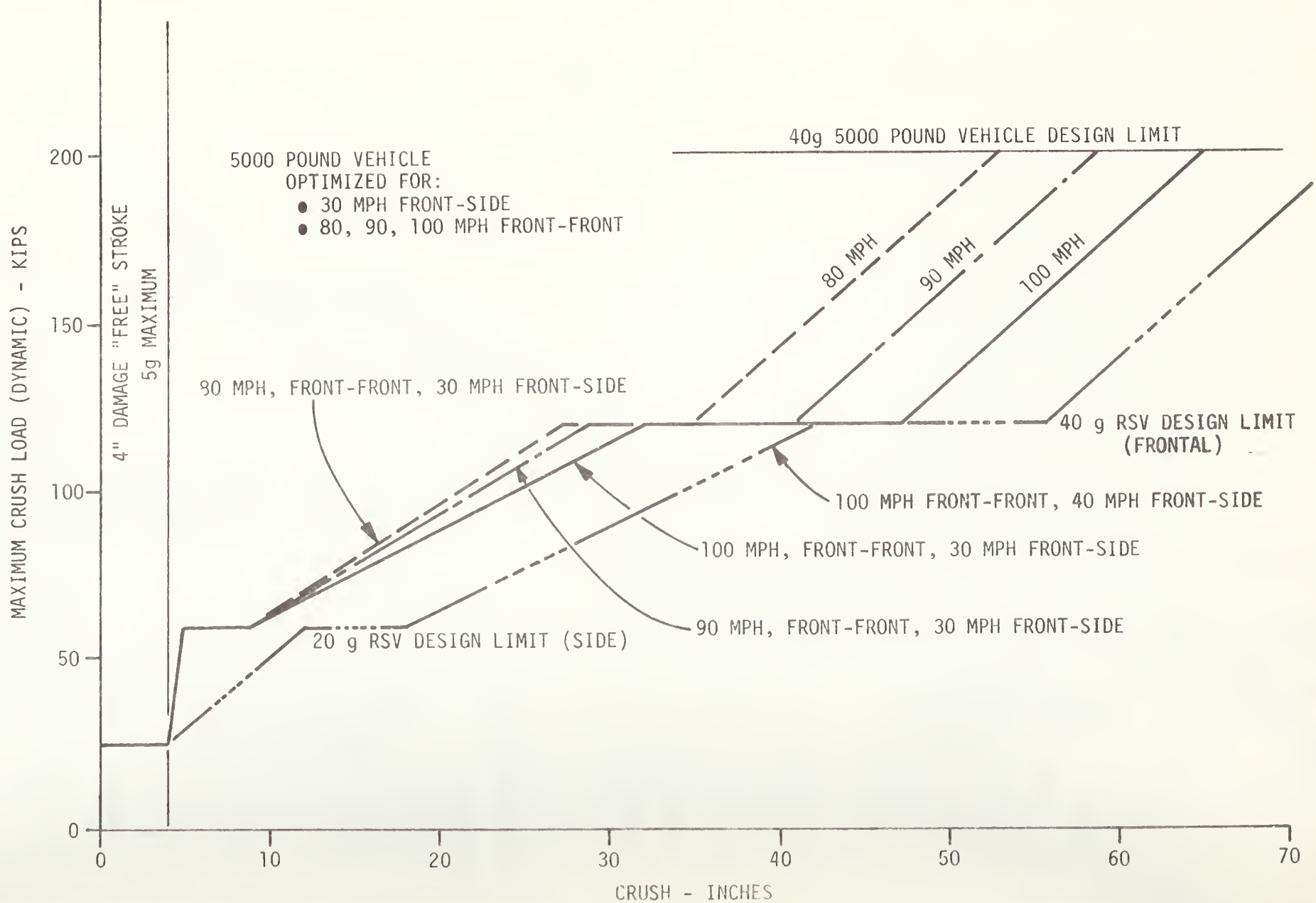


Figure 5-24. Front End Stiffness Characteristics for Vehicle-Vehicle Compatibility, at Various Impact Speeds (Front End Optimized for 30 mph Front-Side Impacts)

speeds for comparison. The improved crush characteristics associated with the vehicle designed to the lower bound velocities are evident.

2.4.1 Structural Systems

This section presents a more detailed discussion of the problem of RSV crashworthiness design, and specifically addresses the crashworthy design requirements for the RSV structural systems. Included here is a study of the relationships existing between design impact speed requirements, societal benefits associated with these requirements and the resulting RSV structural design penalties. The objective here is to determine the design constraints that will provide maximum safety benefits while accruing minimum vehicle penalties (i.e., weight, comfort, styling, etc.), and thereby provide the justification and rationale for the specification Section 2.4.1, Structural Systems.

The descriptions of the components of the structural systems, their interrelationships, safety functions, intrusion levels, and other general requirements for the structural systems are the same as those presented in the guideline IESV specifications.

Benefit/Cost Considerations in Structural Design

This discussion addresses the interrelation between vehicle crashworthiness, societal benefits derived from crashworthy design, and the resulting design penalties. These factors provide the basis for defining the impact speeds for the basic accident modes to which the RSV should be designed from the standpoint of benefit/cost criteria, and provide the primary supporting rationale for the design crash modes defined in specification Figure VIII.

Statistical Data. There is a large amount of statistical data available on vehicle accidents which can be used as a basis for categorizing the basic accident modes for crashworthiness design. Section 3.0, Volume II, Program Definition Foundation, documents the statistical data for the projected mid-80 accident environment obtained during the program definition phase of this study. This data served as a basis for determining and categorizing the basic design crash modes defined therein. Section 3.3.2, Benefit/Cost Analysis Techniques, establishes the methodology that was used to assimilate this data and to condense it into a form that is usable in the investigation discussed here.

Methodology. The methodology developed in this investigation provides a means to compare "benefits" derived from postulated vehicle designs with associated "costs" (or penalties). Recognizing the fact that even with the best of vehicle designs, increased crashworthiness requires added structure (weight) to the vehicle, it is evident that increasing the severity of a given crash mode will necessarily lead to heavier vehicles if set criteria regarding passenger compartment intrusion and deceleration are to be met. The increase in vehicle weight over and above the baseline level (representing current production vehicles) is equated to cost (or penalty) in this analysis. The term benefit, on the other hand, is equal to the "savings in societal cost" which would be realized if fatalities and injuries were reduced as a consequence of increased vehicle crashworthiness.

This methodology then becomes a tool to relate penalties to benefits in search of a most cost effective vehicle design, and ultimately, it helps define optimum speed ranges for each of five basic accident modes considered in this investigation.

Input and Assumptions. Input for this study were derived from several sources:

1. Crashworthiness Weight Study Computer Program (CRASHWT) - developed by AMF and presented in the AMF Tradeoff & Investigation Systems Studies Report DOT HS-800 922.

2. Performance characteristics for restraining systems and interior padding as derived herein.

3. Baseline vehicle component weights - obtained from actual weights of a 1974 Ford Pinto.

4. Distribution of maximum potential societal cost savings per vehicle - derived using the methodology established in Section 3.3.2, Volume II of this final report.

The cost/benefit optimization methodology used is highly dependent on the CRASHWT computer program developed by AMF and consequently, some description of this program (the mathematical model and the basic assumptions of the model) is warranted here. The mathematical model basic to the CRASHWT program may be written as follows:

$$M_{v_{i,j}} = M_{f_i} + E_{c_{i,j}} V_j^2 \tag{1}$$

$$M_{v_i} = M_{f_i} + \text{MAX} \Big|_{j=1}^{n} (E_{c_{i,j}} V_j^2) \tag{2}$$

$$M_v = \sum_i M_{v_i} \tag{3}$$

where,

$M_{v_{i,j}}$ = Total crashworthy weight for vehicle element i, in crash mode j.

M_{f_i} = Functional weight for vehicle element i, without considering crashworthiness.

$E_{c_{i,j}}$ = Energy coupling coefficient for element i, in crash mode j.

V_j = Impact velocity for impact mode j.

M_{v_i} = Total crashworthy weight of vehicle element i considering all j impact modes.

The energy coupling coefficient (E_c) is defined further as follows:

$$E_{c_{i,j}} = M_{design_{i,j}} / V^2_{design_j} \qquad (4)$$

where,

$M_{design_{i,j}}$ = Design weight of vehicle element i, when designed for crash mode j with an impact speed V_{design_j}.

V_{design_j} = Design impact speed for impact mode j.

The energy coupling coefficient defined in equation (4) thus provides the analytical "tie" between impact speed (for a given impact mode) and the vehicle elemental weight. It is assumed that the coupling coefficient remains constant with impact speed. The coupling coefficients normally would be determined from preliminary design calculations of the actual vehicle hardware. However, for this investigation, the energy coupling

coefficients for the RSV were determined by scaling down the appropriate energy coupling coefficients determined for a family sedan ESV structure prototype which was designed, fabricated and tested by AMF during a previous DOT contract. Further, refinements to this derived set of coupling co- [15]
efficients are reserved for the Phase II program wherein actual RSV design data is developed.

The total crashworthy weight of a vehicle may be determined from equation (2) by summing all i elements. The term $\text{MAX}_{j=1}^{n} [E_{c_{i,j}} V_j^2]$ in equation (2) implies that the maximum dynamically coupled weight for element i (considering all j impact modes) is used in the calculation. This further implies that a search is made to determine the impact mode that constrains each element design, and only those critical conditions (maximum elemental weight resulting from exposure to all impact modes) are used.

There are several assumptions that are basic to the CRASHWT program. These are summarized as follows:

1. The vehicle is considered to be a fixed overall design such that no individual element design optimization for any variation in crashworthiness parameters is attempted within the analysis. To do so within a system level parametric study would be a prohibitively large, if not impossible, task. Therefore, the overall basic form of each individual structural element is considered to be non-varying.

2. Constant crash performance is specified. This is defined to mean that maximum intrusion and acceleration levels of the passenger compartment are held invariant throughout the range of variations of crashworthiness requirements. The deceleration pulse shape is constant but the duration may vary. The difference in energy absorption levels is considered wholly within the crashworthy structural elements.

3. Each structural element is considered to have a single critical design condition which controls its initial design. When designed to this condition, the element satisfies all other design requirements. This can be demonstrated by considering a simple beam element. If, for example, two design conditions have to be satisfied, such as axial compression and bending, and the basic external configuration of the beam element is held to be constant, then the two design conditions will result in the same form of beam, but with different section thicknesses. The design requirement resulting in the greater weight is considered to be the critical design condition. The beam element, at the larger weight, can be assumed to satisfy the less severe design requirements. As the critical design requirement is reduced in magnitude, the weight of the element will also be reduced until at some point, the other design condition will become critical, and no further weight reduction will be possible without reducing other design requirements.

4. The analytical formulation considers all energy absorbing elemental weights to be proportional to the square of the controlling impact velocity.

5. Each subsystem and assembly is considered to have a functional design weight. This is the minimum weight possible for each subsystem and is required for conventional functional purposes. Crashworthy weight is any weight in excess of the functional requirements.

As previously noted, one of the data inputs for this investigation are the performance characteristics for restraint systems. It is impossible to determine the benefits gained from a crashworthy vehicle structure unless the effectiveness of a restraint in reducing injuries and fatalities is determined. Determination of restraint effectiveness is a very difficult task, especially in terms of an unbiased measure of effectiveness. Several

researchers, namely, McElhaney, et al, Marks, et al, Warner, et al, have made some in-roads in the determination of several basic performance characteristics of restraint systems. McElhaney's studies for example, suggest belt restraint effectiveness values indicated in Table 5-12. [54, 55, 56]

Table 5-12

Injury Reduction Resulting From the Use of Lap and Upper Torso Belts

Equivalent Barrier Speed (mph)	Impact Speed (mph)	Driver Injury Reduction (%)	Right Front Passenger Reduction (%)
15	30	45	48
20	40	57	60
25	50	68	71
30	60	78	81

Marks, et al, in their study suggest projected fatality reductions for several restraint systems as listed in Table 5-13.

Table 5-13

Relative Performance of Several Restraint Configurations

Restraint Type	Fatality Reduction* (100% Use Factor)	Relative Performance Factor
Lap Belt	17%	.548
Air Cushion	18%	.581
Air Cushion + Lap	29%	.935
Lap + Shoulder Belt	31%	1.0

*Performance for all impact types and all velocities.

With the use of the information in Table 5-12 and the relative performance factors in Table 5-13, an estimate was made of the restraint performance for various restraint configurations as a function of impact velocity. Table 5-14 shows the resulting restraint performance assumed in this study. It was further assumed that the front seats contain either a passive lap + shoulder belt restraint or a deployable + lap restraint (lap belt with 100% use rate).

Table 5-14

Estimated Restraint Performance
(% Injury and Death Reduction)
For "Near-Frontal" Impacts

Equiv. Barrier Speed	Impact Speed	Driver (%)				Right Front (%)			
		Lap	Lap + Shoulder	Deployable	Deploy. + Lap	Lap	Lap + Shoulder	Deployable	Deploy. + Lap
15	30	24.7	45.0	26.1	42.1	26.3	48.0	27.9	44.9
20	40	31.3	57.0	33.1	53.3	32.9	60.0	34.9	56.1
25	50	37.3	68.0	39.5	63.6	38.9	71.0	41.3	66.4
30	60	42.8	78.0	45.3	73.0	44.4	81.0	47.1	75.8

The data in Table 5-14 is plotted in Figure 5-25. It was assumed in this study that the effectiveness of the restraints in side and rear and large oblique impacts are negligible, and that interior padding provides the primary protection for these impact configurations.

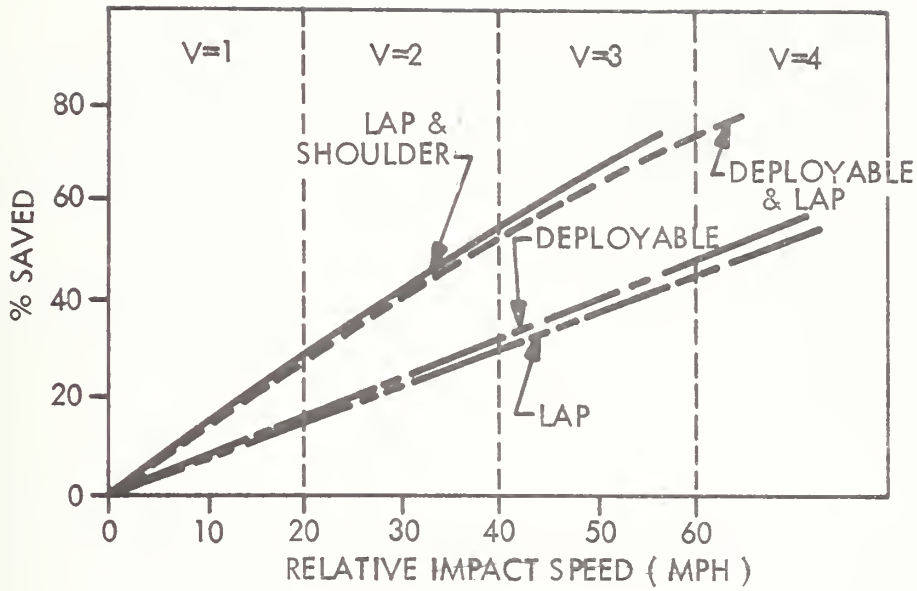


Figure 5-25. Restraint Performance as a Function of Speed

Baseline Vehicle vs the RSV. Because of its appropriate size and weight, and large amount of test data available on this vehicle, the 1974 Ford Pinto was selected to serve as the baseline vehicle.

The level of crashworthiness of the baseline vehicle has been estimated from a series of tests indicating that the Ford Pinto (unmodified) could meet specified deceleration, crush, and passenger compartment intrusion requirements at the following impact velocities: [57]

1. Car-car, front impact 72 mph
2. Car, front-pole impact 30 mph
3. Car, side-pole impact 8 mph
4. Car-car, front-side impact 22 mph
5. Car-car, front-rear impact 32 mph

(The impact modes, j = 1-5, listed above, are the basic impact modes assumed for this investigation.)

If the listed levels of crashworthiness were considered adequate, then no additional improvements would be necessary. However, considerably higher velocity thresholds are envisioned for the RSV, and the obvious question arises: How much higher should these impact velocity thresholds be? As stated before, additional crashworthiness means additional structure (weight) and thus, the question may be rephrased: How much additional weight should be added to the proposed vehicle and how should it be proportioned among the structural systems in order to utilize a limited amount of resources in a most cost effective manner?

The absolute maximum RSV curb weight is limited to 3000 lbs, and thus, the maximum weight which can be added to the baseline vehicle which weighs 2323 lbs is 3000 - 2323 = 677 lbs.

While it is probably safe to assume that if all of the available 677 lbs were well applied, the vehicle's crashworthiness would keep increasing up to that point. It is also conceivable that at some point returns could become so marginal that it would not be desirable to keep on adding more weight in order to gain marginal benefits. Further, the addition of structural weight requires an appropriate increase in the weight of functional systems (suspension, tires, etc.).

The specific methodology used to define the velocity ranges for each of the five accident (crash) modes that are compatible with weight benefit/cost constraints is described in the subsections that follow.

Method of Approach. Two approaches were taken in an effort to optimize the impact velocities and the vehicle weight:

I. In the first approach, each of the basic crash modes were treated individually, independent from the other four crash modes. With the aid of the CRASHWT program, the values for the following items were calculated as a function of increasing impact velocities:

- Added vehicle weight (Δw = cost) for a given impact mode,
- Net benefits (societal cost saved) for given impact mode,
- Benefit/penalty ratios

When these three items are plotted over a coordinate system, they become very useful in comparing penalties paid, with benefits derived. The peak in the benefit/cost (penalty) ratio curve defines the optimum impact velocity (or at least narrows down the range) for that particular accident mode. Table 5-15 and Figure 5-26 show the numerical results and a graphic representation of Approach I. It should be noted that accident mode a is equivalent to j=1, b is equivalent to j=2, etc.

II. In the second approach, instead of considering the individual accident (crash) modes separately, a combination of all five modes is analyzed as a group. Trial combinations are postulated, evaluated and recorded step by step as shown in Table 5-16. The last column in Table 5-16 shows the benefit/penalty ratios for a number of trial combinations. High benefit/penalty ratios are indicative of a good combination. It should be noted that the impact velocities used in the postulated combinations were not picked at random; instead, they were selected near the optimum values of each individual accident mode derived in the first approach.

The bar diagram in Figure 5-27 presents a visual representation of the trial combinations I through IX. The diagram drawn to scale provides a visual means to compare the various combinations and to select promising candidates.

Sample Case. In order to illustrate the mechanics of the two approaches, a sample case of each is described column by column for Tables 5-15 and 5-16 respectively.

Table 5-15. Cost/Benefit Calculation Methodology, Method I

CASE	PENALTY				BENEFIT							COST EFFECTIVENESS
1	2	3	4	5	6	7	8	9	10	11	12	13
	ACCIDENT MODE	CLOSING VELOCITY	W_T	ΔW	POTENTIAL BENEFIT PER ACCIDENT	$\eta \times \beta^{\alpha} \gamma$	ADJUSTED BENEFIT PER VEHICLE	POTENTIAL BENEFIT BASELINE VEHICLE PER ACCIDENT	$\eta \times \beta^{\alpha} \gamma$	ADJUSTED BENEFIT BASELINE VEHICLE	NET BENEFIT VEHICLE (8) - (11)	BENEFIT/PENALTY
		MPH	#	#	$ SAVED	K	$ SAVED	$ SAVED	K	$ SAVED	$ SAVED	$/#
A	a	72	2323	0		BASELINE VEHICLE					0	0
	b	30		0							0	0
	c	8		0							0	0
	d	19		0							0	0
	e	30		0							0	0
B	a	140	4506.9	616.6	0.59 x 5816 = 3431	0.89 x 0.80 = 0.712	2442	0.453 x 5816 = 2634	0.89 x 0.80 = 0.712	1875	2442 - 1875 = 567	567/616.6 = 0.919
	b	60		586.8	0.559 x 16140 = 9022	0.11 x 0.80 = 0.088	794	0.262 x 16140 - 4228	0.11 x 0.80 = 0.088	372	794 - 372 = 422	422/586.6 = 0.719
	c	40		1715.9	0.14 x 16140 = 2260	0.11 x 0.40 = 0.044	99	0.012 x 16140 = 194	0.11 x 0.30 = 0.033	6	99 - 6 = 93	73/1715.6 = 0.05
	d	50		368.2	0.134 x 5816 = 779	0.89 x 0.40 = 0.356	277	0.072 x 5816 = 419	0.89 x 0.30 = 0.267	112	277 - 112 = 165	165/368.2 = 0.448
	e	60		381.4	0.17 x 5816 = 989	0.89 x 0.80 = 0.712	704	0.166 x 5816 = 965	0.89 x 0.80 = 0.712	687	704 - 687 = 17	17/381.4 = 0.044
C	a	120	3468	377.0	0.564 x 5816 = 3280	0.712	2335	2634	0.712	1875	2335 - 1875 = 460	460/377.0 = 1.220
	b	50		322.9	0.443 x 16140 = 7150	0.088	629	4228	0.088	372	629 - 372 = 257	257/322.9 = 0.796
	c	30		868.2	0.105 x 16140 = 1695	0.044	75	194	0.033	6	75 - 6 = 69	69/868.2 = 0.079
	d	40		190.4	0.114 x 5816 = 663	0.356	236	419	0.267	112	236 - 112 = 124	124/190.4 = 0.651
	e	50		213.2	0.170 x 5816 = 989	0.712	704	965	0.712	687	704 - 687 = 17	17/213.2 = 0.080
D	a	100	2775	173.1	0.532 x 5816 = 3094	0.712	2203	2634	0.712	1875	2203 - 1875 = 328	328/173.1 = 1.894
	b	40		112.3	0.312 x 16140 = 5036	0.088	443	4228	0.088	372	443 - 372 = 71	71/112.3 = 0.632
	c	20		322.5	0.06 x 16140 = 968	0.044	43	194	0.033	6	43 - 6 = 37	37/322.5 = 0.11
	d	30		57.0	0.092 x 5816 = 535	0.356	190	419	0.267	112	190 - 112 = 78	78/ 57 = 1.368
	e	40		81.1	0.168 x 5816 = 977	0.712	695	965	0.712	687	695 - 687 = 8	8/ 81.1 = 0.099
E	a	80	2396	30.7	0.475 x 5816 = 2762	0.712	1966	2634	0.712	1875	1966 - 1875 = 91	91/30.7 = 2.964
	b	30		18.2	.18 x 16140 = 2905	0.088	256	4228	0.088	372	256 - 372 = -116	-116/18.2 < 0 (-6.4)
	c	10		38.3	0.02 x 16140 = 323	0.044	14	194	0.033	6	14 - 6 = 8	8/38.3 = 0.209
	d	20		5.7	0.07 x 5816 = 407	0.356	145	419	0.267	112	145 - 112 = 33	33/ 5.7 = 5.78
	e	30		3.7	0.168 x 5816 = 977	0.712	695	965	0.712	687	695 - 687 = 8	8/ 3.7 = 2.162
F	a	60	2326	0.0≈0	0.41 x 5816 = 2384	0.89 x 0.80 = 0.712	1697	2634	0.712	1875	1697 - 1875 = -178	< 0
	b	20		1.3≈0	0.07 x 16140 = 1130	0.11 x 0.55 = 0.060	68	4228	0.088	372	68 - 372 = 304	< 0
	c	0		0.0≈0	0	0.11 x 0.40 = 0.044	0	194	0.033	6	0 - 6 = -6	< 0
	d	10		0.9≈0	0.036 x 5816 = 209	0.89 x 0.40 = 0.356	74	419	0.267	112	74 - 112 = -38	< 0
	e	20		0.0≈0	0.14 x 5816 = 814	0.89 x 0.80 = 0.712	579	965	0.712	687	579 - 687 = -108	< 0

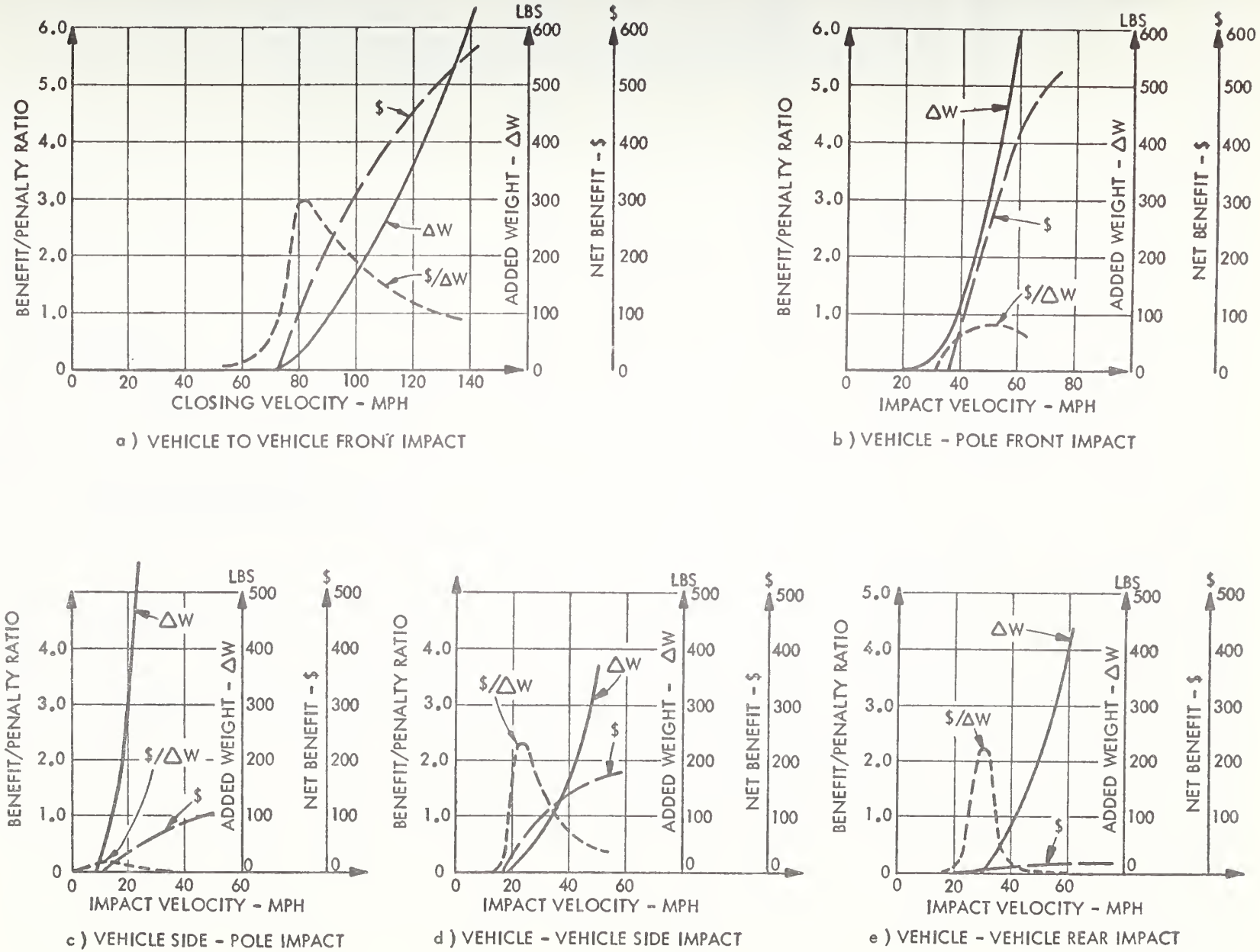
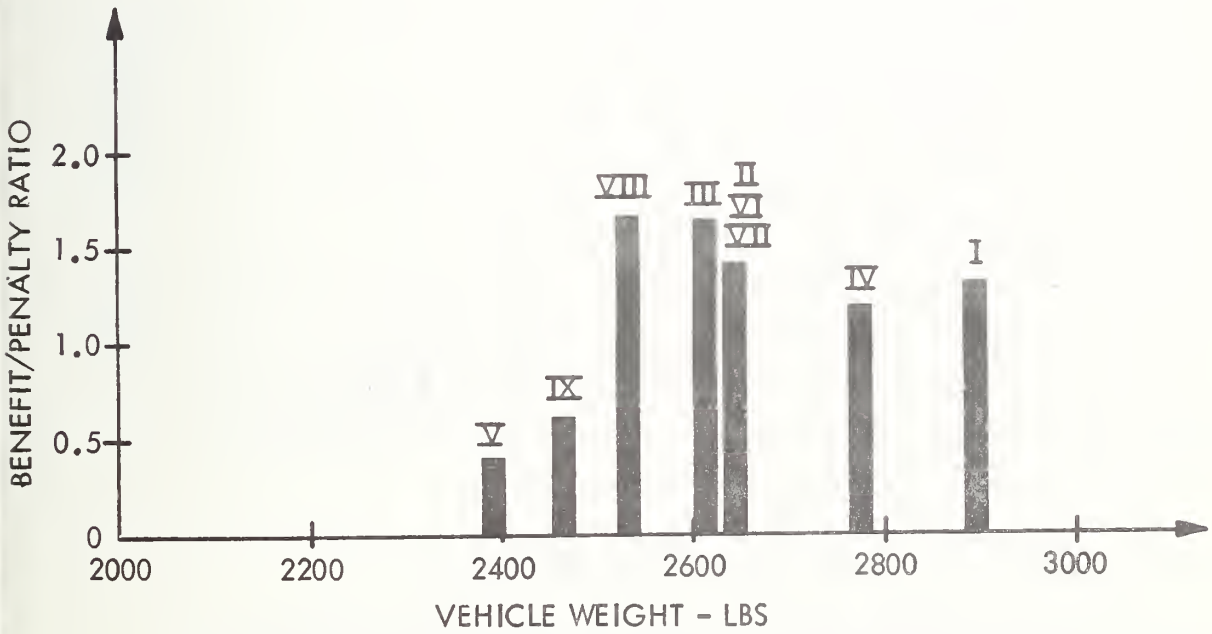


Figure 5-26. Vehicle Weight and Societal Cost Benefits versus Impact Velocity

Table 5-16. Cost/Benefit Calculation Methodology, Method II

CASE	PENALTY				BENEFIT							COST EFFECTIVENESS
1	2	3	4	5	6	7	8	9	10	11	12	13
	ACCIDENT MODE	CLOSING VELOCITY	W_T	ΔW	POTENTIAL BENEFIT PER ACCIDENT	$\eta \times \beta^{\alpha} \gamma$	ADJUSTED BENEFIT PER VEHICLE	POTENTIAL BENEFIT FOR BASELINE VEHICLE PER ACCIDENT	$\eta \times \beta^{\alpha} \gamma$	ADJUSTED BENEFIT PER BASELINE VEHICLE	NET BENEFIT PER VEHICLE (8) - (11)	BENEFIT/ PENALTY RATIO
		MPH	#	#	$ SAVED	K	$ SAVED	$ SAVED	K	$ SAVED	$ SAVED	$/#
I	a b c d e	100 50 20 40 40	2889.6	567	0.532 x 5816 = 3094 0.443 x 16140 = 7150 0.06 x 16140 = 968 0.114 x 5816 = 663 0.168 x 5816 = 977	0.89 x 0.80 = 0.712 0.11 x 0.80 = 0.088 0.11 x 0.40 = 0.044 0.89 x 0.40 = 0.356 0.89 x 0.80 = 0.712	2203 629 43 236 696 3807	0.453 x 5816 = 2634 0.263 x 16140 = 4245 0.012 x 16140 = 194 0.072 x 5816 = 419 0.166 x 5816 = 965	0.89 x 0.80 = 0.712 0.11 x 0.80 = 0.088 0.11 x 0.30 = 0.033 0.89 x 0.30 = 0.267 0.89 x 0.80 = 0.712	1875 374 6 112 687 3054	3807 - 3054 = 753	$\frac{753}{567} = 1.33$
II	a b c d e	100 0(35) 0(10) 40 40	2638.3	315.7	0.532 x 5816 = 3094 0.246 x 16140 = 3970 0.02 x 16140 = 323 0.114 x 5816 = 663 0.168 x 5816 = 977	0.712 0.088 0.044 0.356 0.712	2203 349 14 236 695 3497	2634 4245 194 419 965	0.712 0.088 0.033 0.267 0.712	1875 374 6 112 687 3054	3497 - 3054 = 443	$\frac{443}{315.7} = 1.40$
III	a b c d e	100 40 15 25 35	2619.0	296.0	0.532 x 5816 = 3094 0.312 x 16140 = 5036 0.040 x 16140 = 646 0.080 x 5816 = 465 0.168 x 5816 = 977	0.712 0.088 0.044 0.356 0.712	2203 443 28 165 695 3534	2634 4245 194 419 965	0.712 0.088 0.033 0.267 0.712	1875 374 6 112 687 3054	3534 - 3054 = 480	$\frac{480}{296} = 1.62$
IV	a b c d e	100 40 20 30 40	2775.0	452.4	0.532 x 5816 = 3094 0.312 x 16140 = 5036 0.06 x 16140 = 968 0.092 x 5816 = 535 0.168 x 5816 = 977	0.712 0.088 0.044 0.356 0.712	2203 443 43 190 695 3574	2634 4245 194 419 965	0.712 0.088 0.033 0.267 0.712	1875 374 6 112 687 3054	3574 - 3054 = 520	$\frac{520}{452.4} = 1.15$
V	a b c d e	80 30 10 20 30	2396.0	73.0	0.475 x 5816 = 2762 0.18 x 16140 = 2905 0.02 x 16140 = 323 0.070 x 5816 = 407 0.168 x 5816 = 977	0.712 0.088 0.044 0.356 0.712	1966 256 14 145 695 3076	2634 4245 194 419 965	0.712 0.088 0.033 0.267 0.712	1875 374 6 112 687 3054	3076 - 3054 = 22	$\frac{22}{73} = 0.30$
VI	a b c d e	100 32(35) 8(10) 40 40	2638.3	315.3	0.532 x 5816 = 3094 0.246 x 16140 = 3970 0.02 x 16140 = 323 0.114 x 5816 = 663 0.168 x 5816 = 977	0.712 0.088 0.044 0.356 0.712	2203 349 14 236 696 3498	2634 4245 194 419 965	0.712 0.088 0.033 0.267 0.712	1875 374 6 112 687 3054	3498 - 3054 = 444	$\frac{444}{315.3} = 1.41$
VII	a b c d e	100 0(35) 10 40 40	2638.3	315.7	0.532 x 5816 = 3094 0.246 x 16140 = 3970 0.02 x 16140 = 323 0.114 x 5816 = 663 0.168 x 5816 = 977	0.712 0.088 0.044 0.356 0.712	2203 349 14 236 695 3497	2634 4245 194 419 965	0.712 0.088 0.033 0.267 0.712	1875 374 6 112 687 3054	3497 - 3054 = 443	$\frac{443}{315.7} = 1.40$
VIII	a b c d e	90 35 0(10) 35 40	2527.1	204.1	0.51 x 5816 = 2966 0.246 x 16140 = 3970 0.02 x 16140 = 323 0.105 x 5816 = 610 0.168 x 5816 = 977	0.712 0.088 0.044 0.356 0.712	2112 349 14 217 695 3387	2634 4245 194 419 965	0.712 0.088 0.033 0.267 0.712	1875 374 6 112 687 3054	3387 - 3054 = 333	$\frac{333}{204.1} = 1.63$
IX	a b c d e	80 30 10 30 40	2461.0	138.0	0.478 x 5816 = 2780 0.180 x 16140 = 2905 0.020 x 16140 = 323 0.090 x 5816 = 523 0.168 x 5816 = 977	0.712 0.088 0.044 0.356 0.712	1979 256 14 186 695 3130	2634 4245 194 419 965	0.712 0.088 0.033 0.267 0.712	1875 374 6 112 687 3054	3130 - 3054 = 76	$\frac{76}{138} = 0.56$

ACCIDENT MODE	COMBINATION								
	I	II	III	IV	V	VI	VII	VIII	IX
	IMPACT VELOCITY - MPH								
a	100	100	100	100	80	100	100	90	80
b	50	0(35)	40	40	30	32(35)	0 (35)	35	30
c	20	0 (10)	15	20	10	8 (10)	10	0(8)	10
d	40	40	25	30	20	40	40	35	30
e	40	40	35	40	30	40	40	40	40
TOTAL VEHICLE WEIGHT - LBS	2889	2638	2619	2775	2396	2638	2638	2527	2461
BENEFIT/PENALTY	1.33	1.40	1.62	1.15	0.30	1.41	1.40	1.63	0.56



f) VEHICLE WEIGHT AND SOCIETAL COST BENEFITS VERSUS IMPACT VELOCITY

Figure 5-27. Benefit/Penalty Ratio of Nine Trial Cases

FIRST APPROACH, TABLE 5-15 - CASE "D"

Column	Description
1	Case identification.
2	Accident mode identification.
3	Closing velocities at impact for the individual basic accident (crash) modes. These velocities are varied over a wide range in the five cases in search for the optimum value.
4	Total weight of vehicle if it were designed for all five impact velocities listed under (3). This value is meaningless in the first approach because the impact velocities under (3) were selected to define the individual curves "a" through "e", and are not necessarily design velocities to be used simultaneously. (Column 4 has a significant meaning in the second approach.)
5	Additional weight required (penalty or cost) over and above the baseline vehicle weight dictated by the individual accident modes. Each weight increase is due to the corresponding impact velocity only, all other accident modes being suppressed to the baseline vehicle crashworthiness level.
6	Maximum potential societal cost savings per accident. This is the maximum savings which could be realized if all injuries and fatalities could be prevented from occurring in the postulated accident. These values are obtained from Figure 5-28 which in turn is a plot of the values of Table 5-17.
7	Constants used as multipliers for the values in columm (6), in order to arrive at the adjusted societal cost savings per vehicle, reflecting accident mode distribution, restraining system effectiveness, and interior padding performance.

η = accident mode distribution factor

η_1 = 0.89 vehicle to vehicle impact

η_2 = 0.11 vehicle to rigid barrier impact

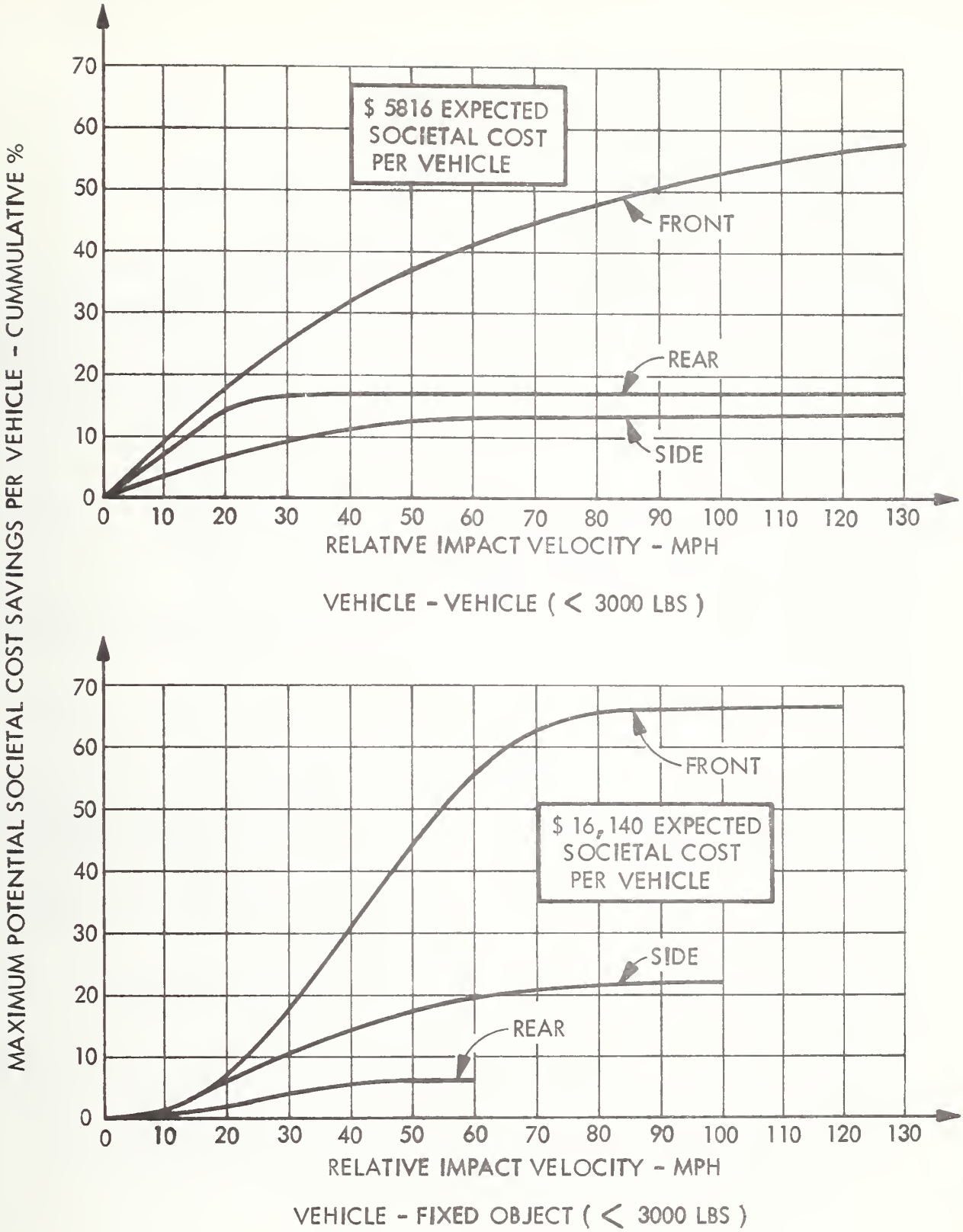


Figure 5-28. Distribution of Maximum Societal Cost Savings Per Vehicle

Table 5-17.

a) VEHICLE TO VEHICLE (< 3000 LBS)

COST SAVINGS PER VEHICLE (%)

IMPACT DIRECTION	RELATIVE IMPACT SPEED - MPH											
	0 - 20	20 - 30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90	90 - 100	100 - 110	110 - 120	120 - 1
FRONT	16.3	14.6 (30.9)		8.2 (39.1)		4.4 (43.5)	3.0 (46.5)	3.5 (50)	2.9 (52.9)	3.6 (56.5)	0.1 (56.6)	1.7 (58.3
SIDE	7.0	4.5 (11.5)		1.2 (12.7)	1.1 (13.8)	0.7 (14.5)						
REAR	13.7	2.0 (15.7)	0.2 (15.9)	0.2 (16.1)		- (16.1)						

TOTAL FATALITIES = 8600
TOTAL INJURIES = 666,850 $ 5816 EXPECTED SOCIETAL COST PER VEHICLE
NUMBER OF INVOLVEMENTS=814,427
TOTAL SOCIETAL $ = 4.71 B

b) VEHICLE - FIXED OBJECT (< 3000 LBS)

COST SAVINGS PER INJURY (%)

IMPACT DIRECTION	RELATIVE IMPACT SPEED - MPH								
	0 -20	20 - 30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90	90 - 100
FRONT	5.5	25.8 (31.3)		26.3 (57.6)		8.5 (66.1)	1.5 (67.6)	0.8 (68.4)	0.4 (68.8)
SIDE	6.2	8.5 (14.7)		3.9 (18.6)	1.7 (20.3)	1.3 (21.6)	1.1 (22.7)	0.1 (22.8)	-
REAR	2.0	1.2 (3.2)	2.9 (6.1)	0.1 (6.2)	-	-			

TOTAL FATALITIES = 6400
TOTAL INJURIES = 116,736 $16,140 EXPECTED SOCIETAL COST PER ACCIDENT
TOTAL ACCIDENTS = 88,607
TOTAL SOCIETAL $ = 1.43 B

NOTE:

- FIGURES IN PARENTHESES ARE CUMMULATIVE PERCENTAGES

Column	Description
	α = restraint system performance, frontal impact (Figure 5-29).
	β = average interior padding performance for lateral impact (Figure 5-30).
	γ = interior padding performance vehicle to vehicle rear impact (Figure 5-31).
8	Adjusted maximum potential societal cost savings per vehicle, per accident mode.
9	Maximum potential societal cost savings per vehicle which could be derived from the baseline vehicle at its present level of crashworthiness.
10	Constants for accident mode distribution, restraining system effectiveness and interior padding performance, corresponding to the values of column (7).
11	Adjusted maximum potential societal cost savings per baseline vehicle, per accident mode.
12	The difference between the adjusted maximum potential societal cost savings obtainable from the postulated new design and the current baseline vehicle in each accident mode is equal to the net benefits per vehicle.
13	The individual net benefit values of column (12) divided by the corresponding penalties of column (5) are equal to the benefit/penalty ratio, a measure of design efficiency.

A number of other cases, similar to sample case "D", were evaluated and summarized in Table 5-15. In each case, accident mode velocities were increased incrementally in order to be able to study the relationship of penalty, benefit, and benefit/penalty ratio to impact velocity. These results were then plotted on a coordinate system for visual comparison and quantitative analysis of the five accident modes (Figure 5-26). As a minimum,

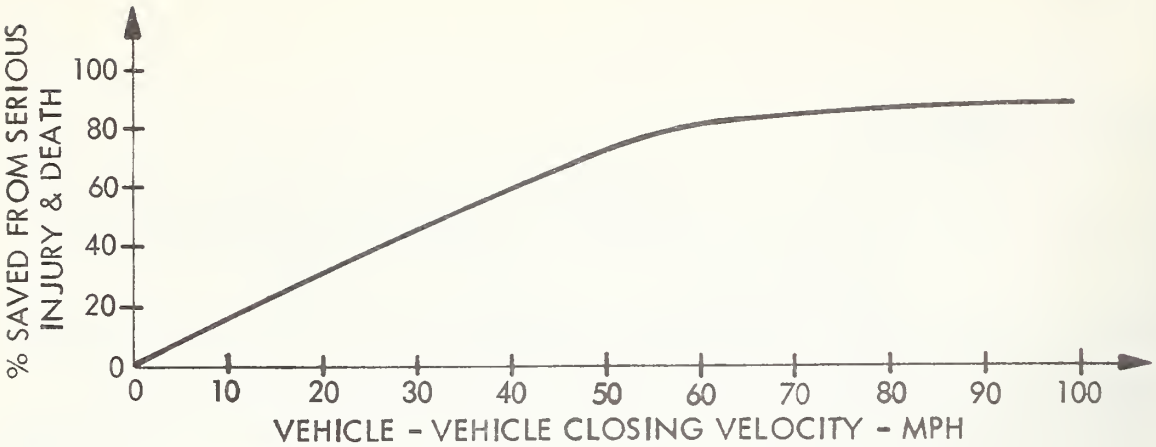


Figure 5-29 Restraint System Performance Front End Impact

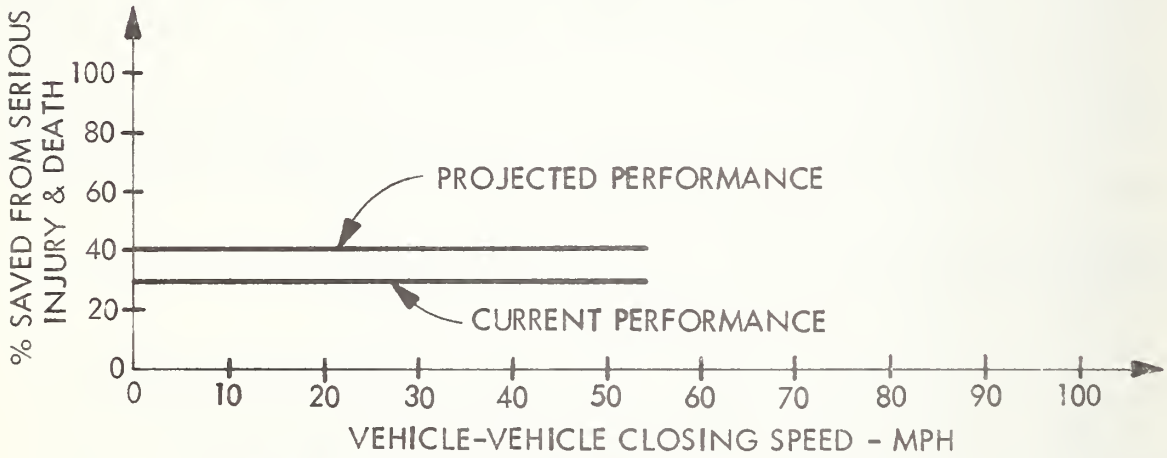


Figure 5-30. Assumed Padding Performance for Lateral Impacts

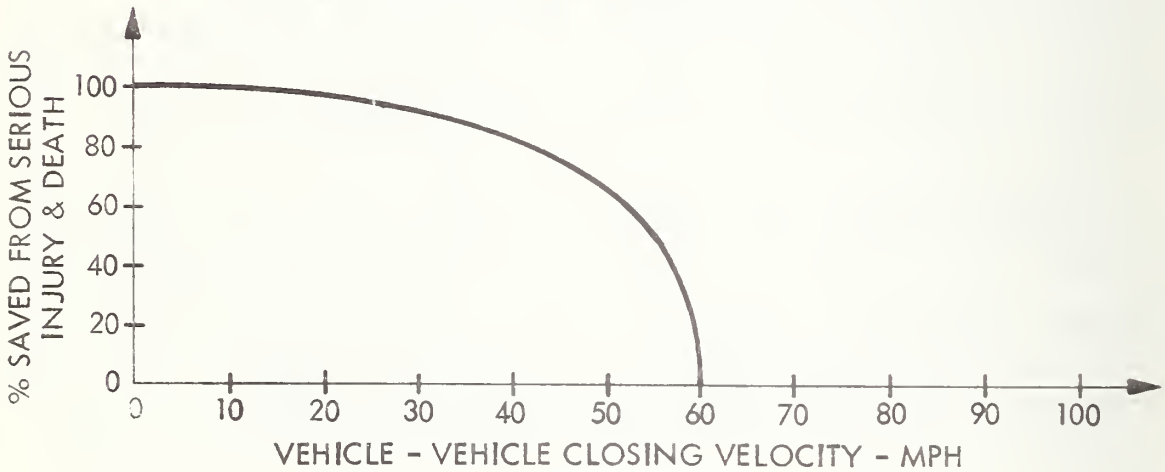


Figure 5-31. Assumed Padding Performance in Rear End Collision

these curves provide a basis for selection of the velocity ranges for use in the second approach analysis, and also serve as a scale for the relative importance of the individual crash modes with respect to each other and to the associated benefits and penalties.

The second approach is a trial and error procedure in which impact velocities (from near the optimum ranges of the first approach) are assigned to the five accident modes "a" through "e", and then the combination is evaluated as a group in a manner similar to that used in the first approach. Several combinations with the impact velocities varied slightly are evaluated in an effort to search for the most cost effective combination. A sample case description of this approach follows.

SECOND APPROACH, TABLE 5-16 - CASE "II"

Column	Description
1	Case identification
2	Accident mode combination
3	Impact velocities for each accident mode. These velocities are selected either near the optimum range based on the results of the first approach, or they were intentionally reduced to very low values or to zero, in order to study the sensitivity of this analysis to variations in the individual crash modes. Based on this type of experimentation, it was determined that in certain circumstances, designing for one accident mode will automatically raise the crashworthiness in another accident mode. This occurred in this sample case, where the 100 mph velocity of accident mode "a" resulted in crashworthiness of mode "b" at a 35 mph impact velocity, even though "b" had been set at zero initially. Thus, the benefits were computed based on 35 mph (this velocity is indicated in parenthesis in column (3)). In the same way, accident mode "d" at 40 mph resulted in a 10 mph capability to mode "c" even though it too had been set at zero initially.

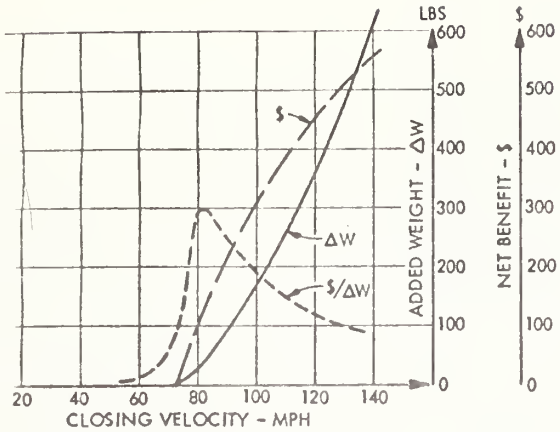
Column	Description
4	Total weight of the vehicle designed to meet the requirement set forth in column (3).
5	Difference in weight between the baseline vehicle and the vehicle designed for the postulated impact velocities. This increase in curb weight over and above the baseline vehicle is termed "penalty" in this analysis, and is used later in calculating the benefit/penalty ratio.
6	Maximum potential societal cost savings per accident which would be realized if all fatalities and injuries would be prevented under the postulated impact velocities. These values are obtained from Figure 5-28.
7	Constants used as multipliers for the values in column (6) in order to obtain the adjusted societal cost savings per vehicle reflecting accident mode distribution, restraint system effectiveness, and interior padding performance (Figures 5-29 through 5-31).
8	Adjusted maximum potential societal cost savings per vehicle, per trial case.
9	Maximum potential societal cost savings which can be realized from the baseline vehicle at its current crashworthiness.
10	Constants for accident mode distribution, restraint system effectiveness, and interior padding performance (correspond to values in column (7)).
11	Adjusted maximum potential societal cost savings per baseline vehicle at its current level of crashworthiness.
12	The difference between the totals of column (8) and column (11) is equal to the net benefit which can be derived from the vehicle designed to the requirements of column (3). This value is used in combination with corresponding values of column (5) to calculate the benefit/penalty ratio.

Column	Description
13	Benefit/penalty ratio. This ratio is a measure of cost effectiveness in design. It must be noted that while the highest benefit/penalty ratio may identify the most cost effective trial case, the need for higher velocity thresholds may dictate the selection of a different trial case with a lower benefit/penalty ratio. Nevertheless, this methodology makes it possible to select from among a large variety of trial cases that particular case which satisfies direct design goals and at the same time has still a relatively high efficiency rating.

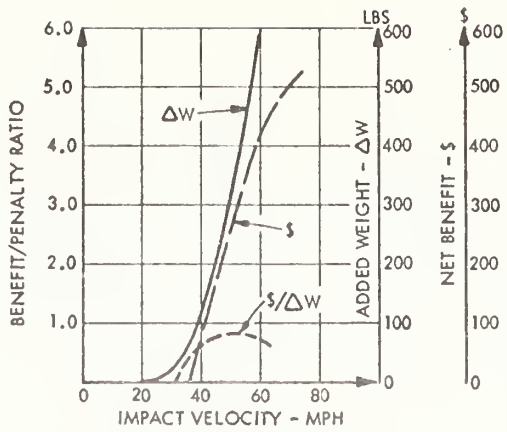
Figure 5-27 shows the various trial cases in the form of a bar diagram.

Summary of Cost/Benefit Combinations. The results of two analytical approaches, presented in Figures 5-26 and 5-27, are combined in Figure 5-32 for ease of reference. The following observations are made from graphs depicting the five crash modes of interest:

- Typically for all five modes, the penalties or weight costs (Δw) rise at a rapid rate with increasing velocities.
- The net benefits (societal cost savings) also rise with increasing velocities, however, at different rates for the various accident modes. For mode "a", the benefits increase sharply at first with increasing velocities and continue to increase at a somewhat lower rate. This is also true for modes "b" and "d". However, in contrast, is the incremental gain in benefits for modes "c" and "e". For these modes, the gain in benefits for increased impact speeds are conspicuously lower. Typically, all net benefit curves are flattening out at higher velocities.

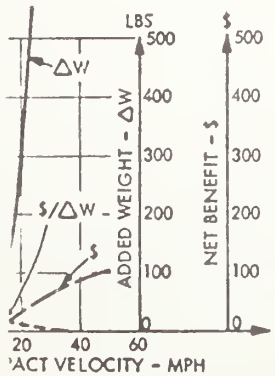


a) VEHICLE TO VEHICLE FRONT IMPACT

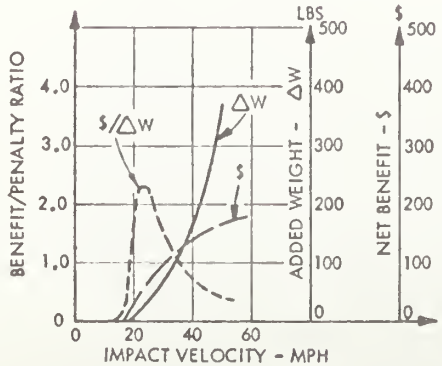


b) VEHICLE - POLE FRONT IMPACT

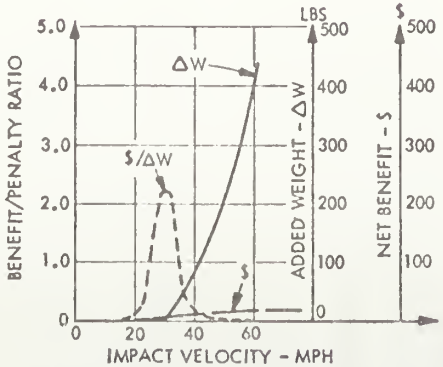
ACCIDENT MODE	COMBINATION								
	I	II	III	IV	V	VI	VII	VIII	IX
	IMPACT VELOCITY - MPH								
a	100	100	100	100	80	100	100	90	80
b	50	0(35)	40	40	30	32(35)	0 (35)	35	30
c	20	0 (10)	15	20	10	8 (10)	10	0(8)	10
d	40	40	25	30	20	40	40	35	30
e	40	40	35	40	30	40	40	40	40
TOTAL VEHICLE WEIGHT - LBS	2889	2638	2619	2775	2396	2638	2638	2527	2461
BENEFIT/PENALTY	1.33	1.40	1.62	1.15	0.30	1.41	1.40	1.63	0.56



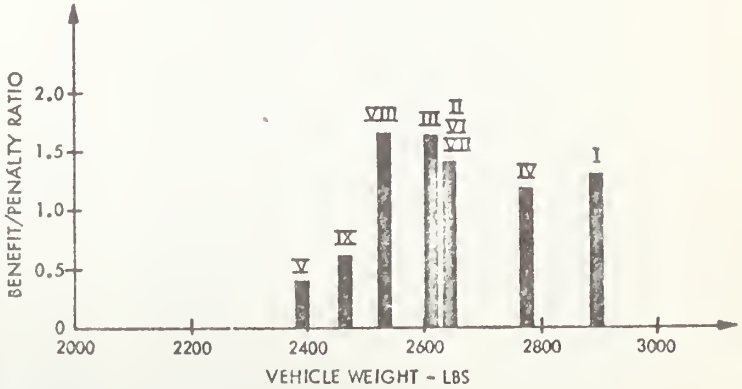
HICLE SIDE - POLE IMPACT



d) VEHICLE - VEHICLE SIDE IMPACT



e) VEHICLE - VEHICLE REAR IMPACT



f) VEHICLE WEIGHT AND SOCIETAL COST BENEFITS VERSUS IMPACT VELOCITY

Figure 5-32. Summary of Cost/Benefit Combinations

- The benefit/penalty curves ($/Δw) peak out at different impact velocities for each of the five crash modes. The peaks identify the impact velocity of the most cost effective design. The numbers of fatalities and injuries at these optimum levels may be still higher than desirable; for this reason, the specifications criteria may call for higher velocities than the optimum values indicated by the graph. However, these curves represent the best current data used to establish the lower limit of impact velocities.

Several conclusions can now be made regarding the impact design requirements for the RSV. First, Figure 5-32 shows that crash combination VIII consisting of the following impact modes

- Car-car front impact at 90 mph
- Car-pole front impact at 35 mph
- Car-car side impact at 35 mph
- Car-car rear impact at 40 mph

results in the maximum benefit/cost ratio (cost = weight increase) when compared to the remaining impact combinations considered. The second best benefit/cost ratio occurs with combination III with a ratio very close to combination VIII. However, the vehicle weight for combination III is 2619 lbs compared to 2527 lbs for combination VIII. Considering the emphasis that is currently being placed on fuel economy and efficient use of natural resources, and the system penalties previously described for the RSV - large car encounter at the 100 mph impact speeds, it appears reasonable that combination VIII would provide a near optimum crashworthiness design requirement for the RSV.

It is apparent from Figure 5-32 that the side-pole impact mode is a very inefficient mode for obtaining improved RSV crashworthiness. The benefits to be gained are very low and the weight penalties are extremely high. This mode, therefore, is not included as a design requirement.

However, as noted in the table in Figure 5-32, crashworthiness to 8 mph in the side-pole impact mode is obtained by the functional and car-car side impact impact design requirements. Thus, the benefits associated with 8 mph side-pole capability were assumed in the benefit/cost conclusions.

It is noteworthy that the vehicle configuration assumed for the RSV in the CRASHWT computer program is the same as the baseline vehicle (1974 Ford Pinto). This configuration includes a producible all low carbon steel sheet metal body and a relatively heavy driveline package. Weight reductions from the estimated vehicle weight of 2527 pounds can be made with judicious use of lightweight and/or high-strength materials and a lighter driveline package.

2.4.1.1 Front Structure

The front structure of the RSV must be designed to limit both the acceleration and intrusion of the passenger compartment during frontal impacts without being overly aggressive against a weaker structure (e.g., the side structure of the RSV). In developing performance specification for the RSV front structure, it is recognized that two diametrically opposing requirements must be satisfied; that is, the structure should be sufficiently "hard" to limit passenger compartment intrusion but sufficiently "soft" to limit the accelerations of the occupants of the vehicle in question as well as the occupants of the other vehicle(s) involved in the collision. The following structural performance limitations are assumed for the RSV:

Impact Direction	Maximum* Intrusion (in)	Maximum Acceleration (g's)	Maximum Impact Load (kips)
Front	3.0	40.0	120.0
Side	3.0	20.0	60.0
Rear	3.0	40.0	120.0

*Additional intrusion is permissible with sufficient technical justification.

The assumed acceleration limits represent upper limits of vehicle acceleration which can be accommodated by an effective restraint. These same limits were complied with in previous ESV work, indicating the feasibility of attaining these same requirements on the RSV.

To insure compatibility between the RSV and other vehicles operating in the same traffic environment mix, it is necessary to develop and enforce a common structural performance standard for all vehicle sizes. The section, System Level Considerations, dealt with this problem and developed idealized front structure characteristics for various impact design speeds. With the impact design requirements specified in the section on Benefit/Cost Considerations in Structural Design, the front structure performance standard was updated as shown in Figure 5-33. This set of curves represents the upper bounds for the front structure load-deflection characteristics for the RSV and a 5000 pound vehicle, considered as the maximum threat to the RSV in the mid-80 environment. It is re-emphasized here that there are indications that the large car population (4000-5000 pound vehicle) may be significantly less than that projected in this final report, and consequently, a smaller "large" car may possibly enter the projected vehicle mix in the final design of the RSV. Another evaluation is indicated early in Phase II, as more firm data relating to car size mix trends is accumulated.

An important consideration in the design of a crashworthy front structure is the development of adequate load paths throughout the structure during impact so that the structural system can function as intended. A key structural element in developing the desired load path is the front bumper. The bumper must be designed to be compatible with other striking or impacted surfaces and to minimize tendencies toward an override/underride situation during impact. To minimize the override/underride tendencies, the bumper must be properly shaped to prevent "ramping", and must be located at a standard height which is consistent for all vehicle sizes. A consideration

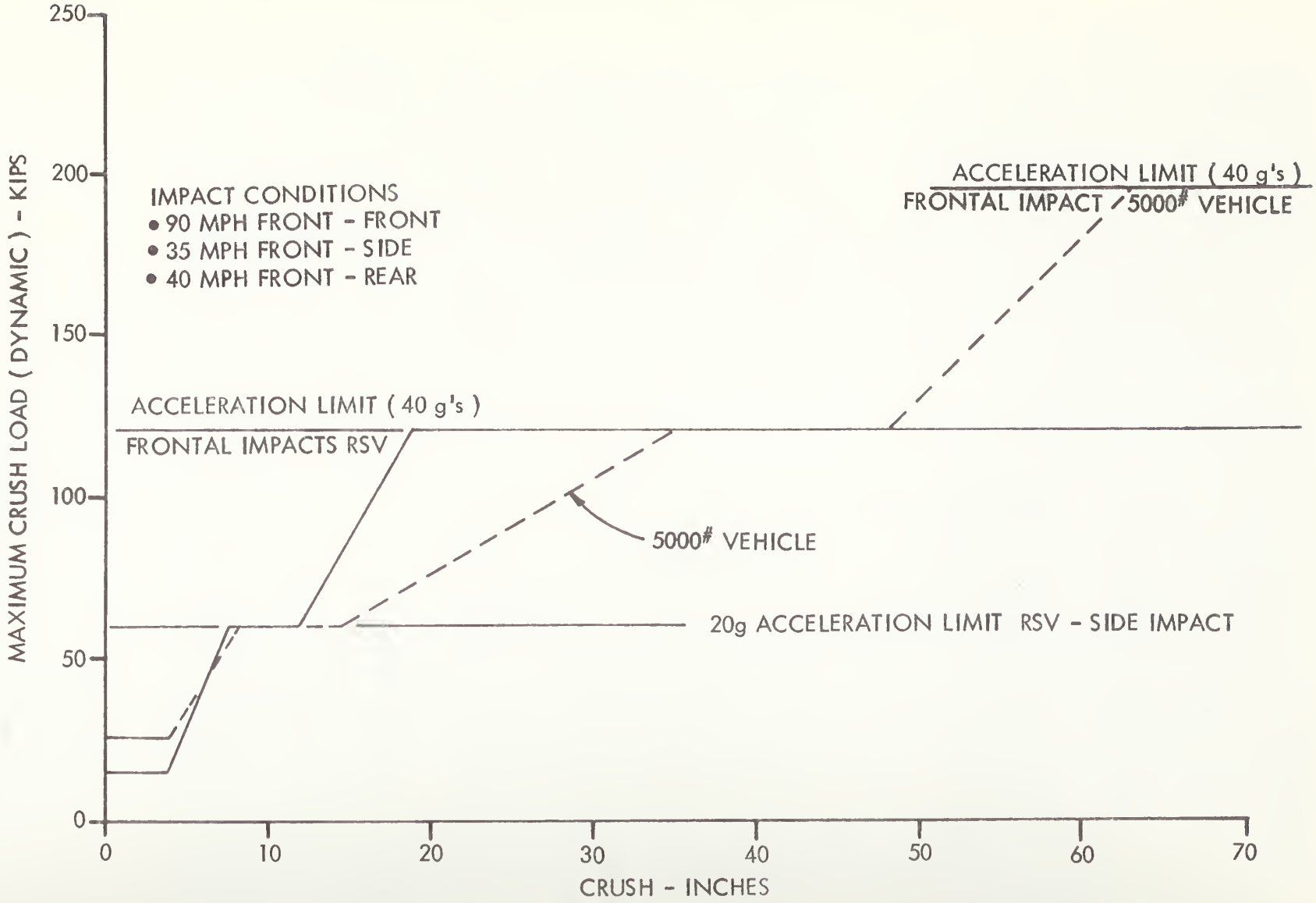


Figure 5-33 Front End Stiffness Characteristics for Vehicle - Vehicle Compatibility

in the selection of the standard bumper height is the resulting interface occurring during a front-side collision. For conventional vehicles with a 4-inch bumper at a height (measured to the center of the bumper) of approximately 17 inches, the point of impact for a front-side encounter occurs well above the rocker panel. This configuration requires the side structure consisting of the "A", "B", "C" pillars and door assembly to "beam" the reaction loads into the more rigid floor structure. This "beaming" action can introduce significant weight penalties and design complexities. In a side impact, it is much more efficient, structurally, to interface the bumper directly with the rocker panel during a front-side collision, as shown in Figure 5-34, thereby allowing a direct load path into the impacted vehicle floor structure.

To determine an ideal bumper height for car-car, front-side collisions, an evaluation of the rocker panel location for the RSV must be made. Figure 5-35 shows a cross section of the RSV indicating the heights of the critical rocker panel and the lower door structural members as determined by preliminary design studies. Also shown is the bumper centerline location for both static and dynamic conditions. It has been determined for the RSV that panic braking preceding impact will cause the bumper to drop in height approximately 4 inches. With this assumption, it appears that a 14 inch static bumper height (maximum) is desirable for the front-side accident mode.

To evaluate the effect of such a requirement on the large vehicles, which are generally characterized by long overhangs and consequently, are more critical from ramp break or angle factors, consider Figure 5-36 which indicates the SAE J689 design requirements for vehicle ground clearance. As shown, the minimum bumper height H is determined from overhang L and bumper depth D. It is estimated that for the large vehicles, the maximum feasible overhang is approximately 34 inches. Thus, for an 8 inch bumper depth, the minimum bumper height is $H_{MIN} = 34 \text{ TAN } (16)^\circ + 4 = 13.7$ inches which appears to satisfy the bumper interface requirements of 14 inches rather well.

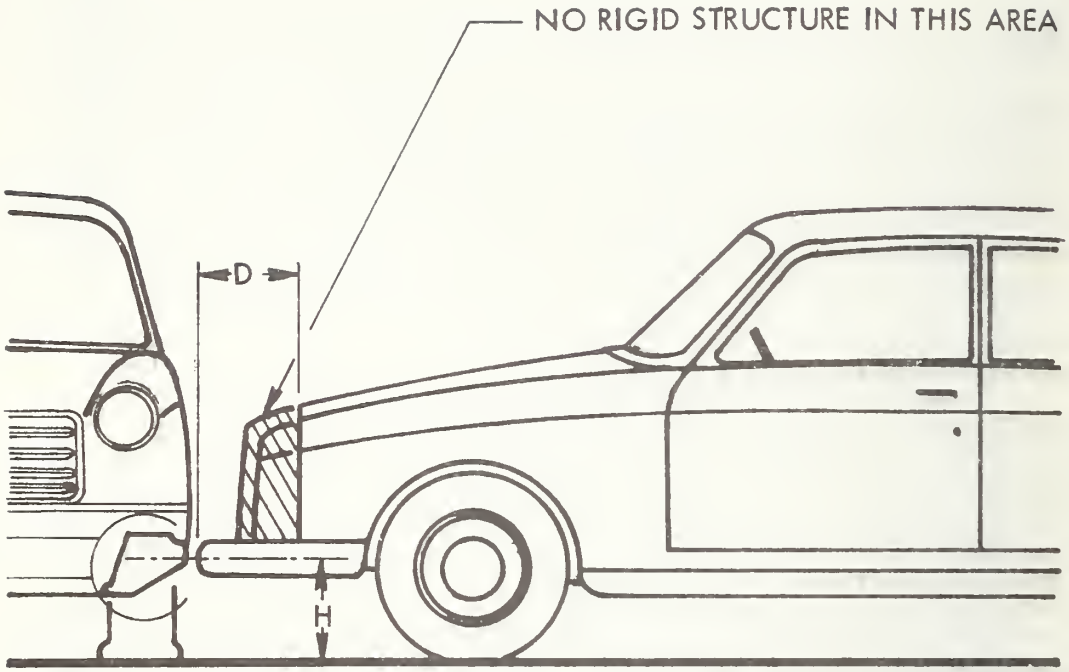


Figure 5-34. Front Structure for Vehicle-Vehicle, Front-Side Compatibility

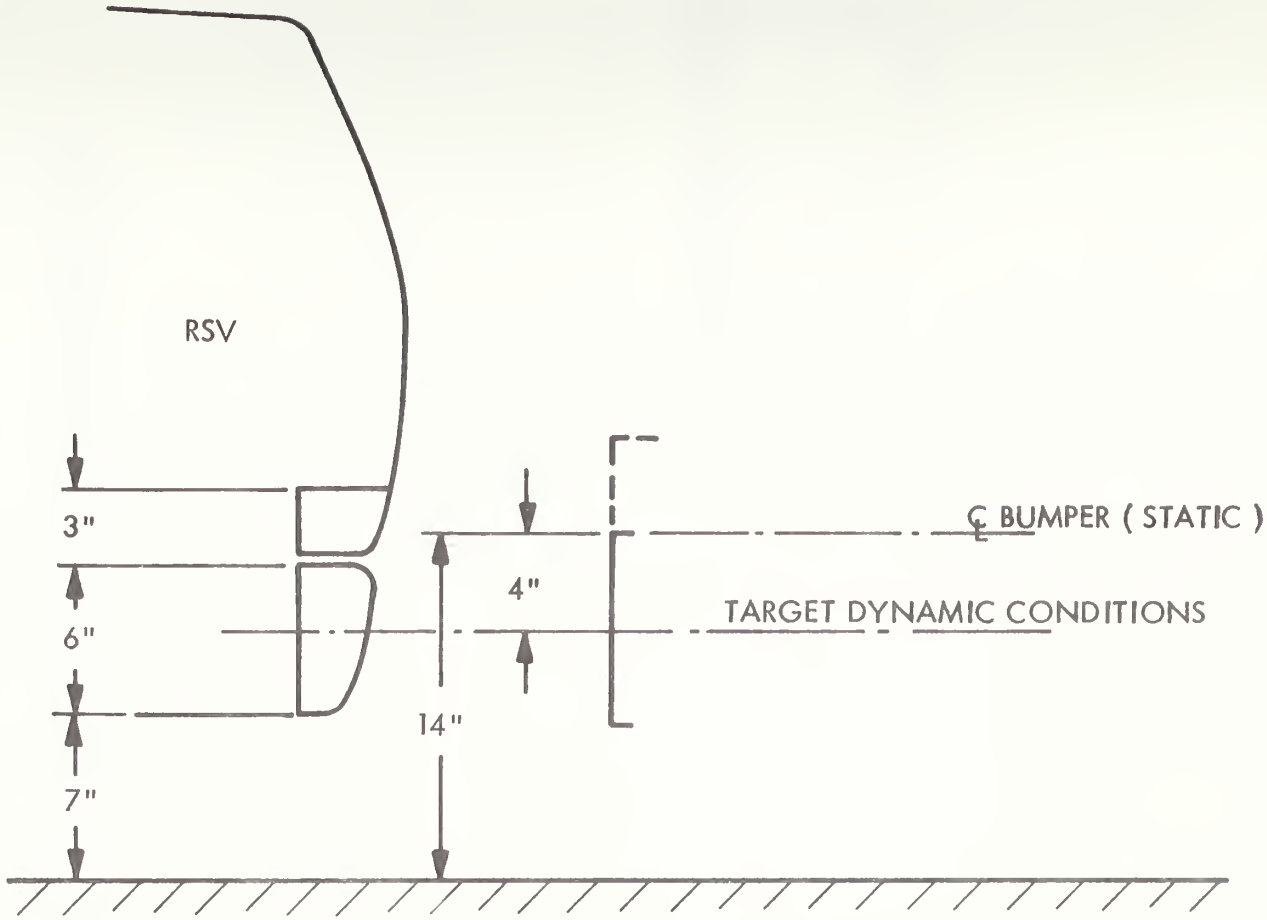
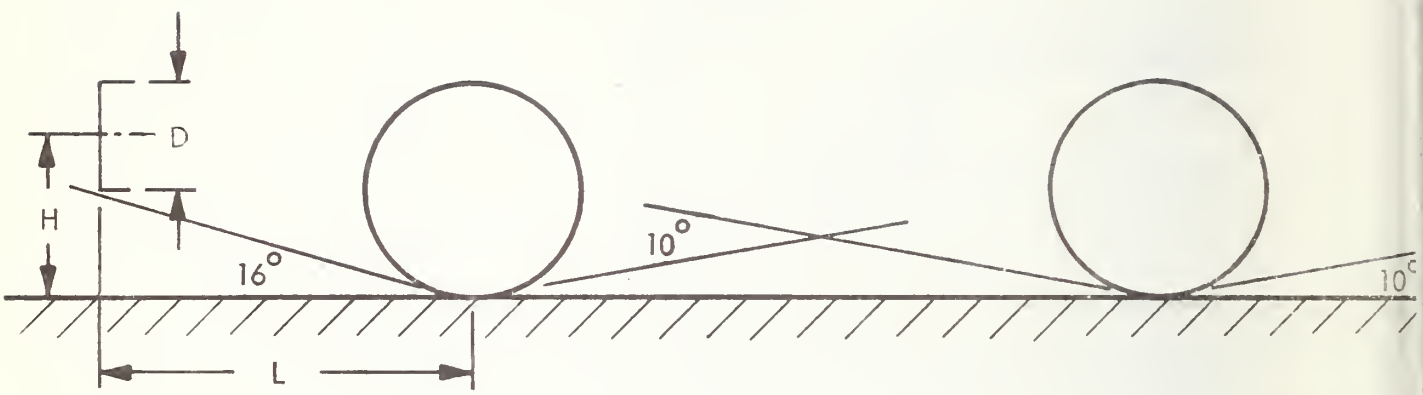


Figure 5-35. Bumper Height Requirements for Front-Side Impact Compatibility



$$H_{MIN} = L \text{ TAN } (16^{\circ}) + \frac{D}{2}$$

REFERENCE: SAE J689

Figure 5-36. Design Requirements for Bumper Height Location

As mentioned earlier, another consideration in vehicle bumper design is underride/override. During this motion, several bumper factors are known to influence the zones impacted by the vehicle bumper during a crash; these are:

a. Bumper height mis-match

b. Undesirable ramping effect

c. Insufficient bumper depth

Factors a and b can be corrected by establishing a common bumper height for all vehicles (as previously prescribed) and by properly profiling the bumper to eliminate ramping. Factor c, however, requires additional study since the required bumper depth will depend on the protection zone requirements, which are in turn determined from vehicle braking kinematics. It has been estimated that with anti-dive characteristics during panic braking at 50% load, the RSV front bumper will drop approximately 4 inches while the rear bumper will rise approximately 2-1/2 inches relative to the static position. Therefore, a reasonable bumper depth appears to be 8 inches which will provide a minimum bumper interlocking of 1-1/2 inches.

A final design consideration for the RSV front structure is the set-back distance D (see Figure 5-35) required to eliminate contact between the relatively soft mid-section of a vehicle side structure in a front-side collision and the "hard" structure comprising the front end of the impacting vehicle. The set-back distance D should be, as a minimum, the crush distance anticipated for the front structure for the design impact speed of 35 mph. For the RSV, a set-back distance of at least 12 inches is required.

To obtain interface compatibility with the RSV, the larger vehicles in the projected vehicle population will require a corresponding set of minimum bumper dimensions in order to accommodate the effect of underride/override motions.

2.4.1.2 Side Structure

The prime crashworthy requirement for the side structure is to maintain the structural integrity of the passenger compartment in front, side, rear and rollover impacts. The most demanding impact configuration from the standpoint of the side structure design is that involving direct impact to the side structure. In previous ESV work, two side impact configurations were used to constrain the side structure design; these were:

- 30 mph, car-car, front-side collision
- 15 mph side/pole, impact (point of impact at midspan of door)

The benefit/penalty findings presented in the Cost/Benefit Considerations in Structural Design section, indicate that the side pole impact configuration is an undesirable design requirement since the benefits to be gained are very minimal and the resulting penalties (in terms of vehicle weight) are very severe. Additionally, the cited study shows that a near optimum (maximum benefit/penalty ratio) occurs for front-side design impact speeds to 35 mph.

Based on the findings of this benefit/cost study, a reasonable design requirement for the RSV side structure is to accommodate front-side collisions to 35 mph. It is to be noted that in the study, the car-car front-side impact configuration was conservatively assumed to be a "normal" front-side configuration where the two vehicles are orthogonal with one another. It is conceivable that for oblique impact configurations, the design requirement could be significantly different. These oblique impact modes are discussed in a subsequent section entitled, Oblique Impacts.

2.4.1.3 Roof Structure

The primary requirement for the roof structure is to protect the occupants from excessive roof crush during rollover impacts. A study by Huelke indicates that there is no significant statistical relationship [34]

between unbelted occupant ejection and roof crush nor between lap belted injuries and the amount of roof crush. The study concluded that a roof crush standard would not reduce the interior impact hazard to the occupant. However, owing to the fact that a vehicle's roof structure is the prime intrusion limiting structure in rollover, it is important that sufficient structural integrity be maintained to prevent total catastrophic collapse of the roof in rollover. On this basis, it seems reasonable to enforce some minimum performance standard for the roof structure. With the lack of sound statistical data relating traveling speed prior to rollover to the final tripping speed at the start of rollover, engineering judgment must be used in specifying a rollover impact speed. Considering that in the 1985 environment, a vehicle traveling at the maximum posted speed limit of 55 mph will probably be in a braking and/or skidding mode prior to tripping, it seems reasonable to assume that the vehicle rollover speed will be significantly less than the vehicle traveling speed, probably in the vicinity of 30 mph. For this performance, a lateral rollover speed of 30 mph is specified. (The overturning immunity specifications make it unlikely that rollover would occur on a planar road surface. Therefore, a tripping source, such as a curb or ditch, is considered as a major factor inducing rollover.)

2.4.1.4 Rear Structure

The rear end crash modes are much less severe, from a design standpoint, then either a frontal or side impact owing to the moderate design impact speed requirement of 40 mph (relative impact speed), favorable acceleration limits (40 g's), and the available crush space (generally greater than the crush space offered by a side structure. Nonetheless, to insure vehicle-vehicle compatibility for all crash modes, the rear structure must be designed to accommodate a vehicle front structure having stiffness characteristics defined in Figure 5-33.

The rear bumper functions are the same in a rear end collision as are those for the front bumper in a front end collision, and hence, the discussion for the front bumper is applicable here.

Oblique Impacts

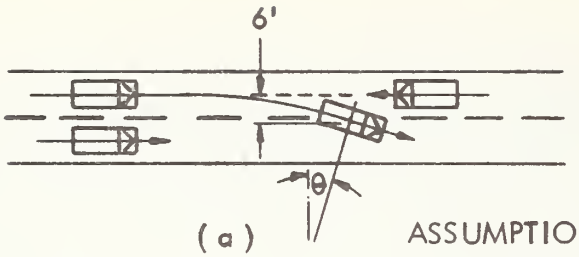
The preceding discussions addressed primarily the "normal" vehicle impact involving collinear or orthogonal vehicle configurations. The dynamic interactions resulting from these impacts are relatively easy to understand and to simulate analytically. The question that arises, however, is: How realistic are the "normal" impact configurations and do these impact configurations constitute the critical configurations for design? Conceivably, the most critical impact configuration for design could involve an oblique impact where the vehicle and its occupants are exposed to axial and lateral accelerations simultaneously. Unfortunately, the dynamic interactions resulting from oblique impacts is not as clearly understood as is that resulting from normal impacts. To gain some basis for understanding how realistic the normal impact modes are, and the significance of directionality in "real world" accidents, it was necessary to investigate the possible pre-crash configurations of vehicles and to determine the extreme attitudes these vehicles can physically acquire during normal driving and under panic conditions. (Statistical data on oblique impact accidents, particularly in terms of the variables of interest, impact angle, speed at impact, experienced injuries, frequencies, etc., is lacking, and therefore, this analysis was undertaken.) A theoretical study by Grime and Jones serves as [58] a basis for the discussion that follows.

Consider the head-on impact configuration involving two automobiles. Because of the nature of this accident mode, the majority of these accidents will occur while both vehicles are traveling on the same road in opposite directions and will be predominantly asymmetrical collisions. The most frequent maneuvers and the probable angles between the vehicles as determined by Grime and Jones are:

(1) Colliding with an opposing vehicle when overtaking. The colliding vehicles may be on parallel paths or at a small angle, as in the case where one vehicle is just pulling out to overtake or failing to get back after overtaking (see Figure 5-37a). A car traveling at 40 mph and overtaking another on a straight road, say 20 ft wide, has to move back to the near side by about one car width, say 6 ft, to miss an oncoming car, or by, say 4 ft to collide head-on. The cars are all assumed to be traveling in the middle of the appropriate lane at the beginning of the maneuver. If the turn is made with a sideways acceleration of 0.5 g (a drastic turn), the radius of curvature of the turn = $r = V^2/0.5\ g = 58.7^2/16 = 212$ ft. The angle which the axis of the car makes with the direction of the road (the angle of yaw) is then approximately $\cos^{-1}(212/218) = 14°$ for a 6 ft sideways movement and 11° for a 4 ft movement. The angle between the directions of motion of the two colliding vehicles might be less than this if the other car took an avoiding action by turning away or if the movements of the first car were not so drastic.

(2) Colliding with an opposing vehicle while maneuvering a curve. If swerving wide on curves is merely a case of controlled encroachment on the opposite lane, the angles between the directions of motion of the two cars are likely to be very small; for example, if the radius of curvature of the curve is as little as 250 ft, a similar calculation to that for the overtaking case shows that the angle at impact would probably be no more than about 3°.

If the speed round the curve is so high that steering control is lost as the result of a front wheel skid, the vehicle will go straight on (see Figure 5-37b) and the angle is calculated in the same way as in the overtaking case. The radius of the bend is again assumed to be 250 ft. To move 6 ft across the road results in an angle of $\cos^{-1}(250/256) \sim 12°$ with the opposing traffic. Curves of such a small radius of curvature are not common on main roads.

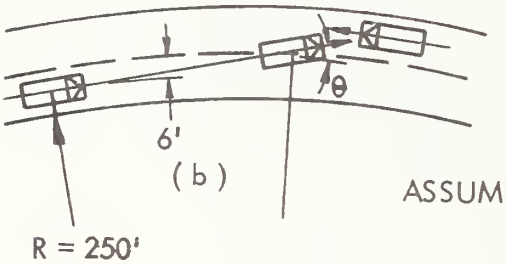


(a)

ASSUMPTIONS:

$a_t = .5g$

V = 40 MPH

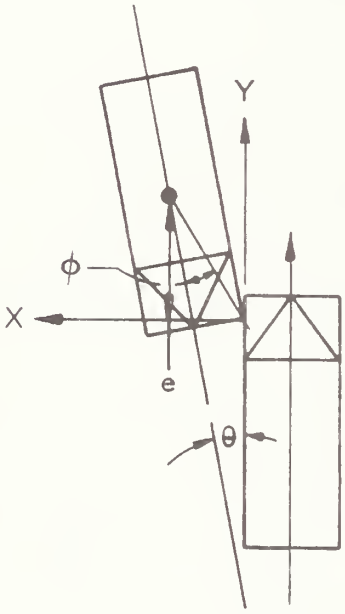


(b)

ASSUMPTIONS:

$a_t = .5g$

$V \cong 40$ MPH



ASSUMPTIONS:

- θ = SMALL
- V = HIGH
- CONTACT POINT ALONG SIDE

(c)

Figure 5-37. Oblique Impact Configurations Evaluated in Theoretical Analysis

(3) Collisions of vehicle out of control. If there is loss of control caused by locking of rear wheels with consequent rotation of the vehicle, the angle which the vehicle makes with the path of oncoming traffic may have any value up to 90°, and the center of gravity of the car may move at a small angle to the axis of the road.

(4) Intersection Collisions. Head-on collisions at angles up to 45° may also occur when vehicles turn across an oncoming traffic stream, usually at low speed, either when emerging from or entering a side road, a garage or house entrance.

The preceding analysis indicates that for the majority of head-on collisions, the relative angle of impact can be expected to be small (under 15°). Frontal impacts involving large relative angles (nearing 45°) will result from either loss of control or from intersection type collisions. The loss of control case can occur at relatively high speeds and consequently, represents a critical design condition. However, with the improved handling and braking performance characteristics anticipated for vehicles in the 1985 time frame, the frequency of these out-of-control collisions is considered to be low. Therefore, it is assumed that the impact configuration involving large angles at impact will be primarily an intersection collision.

Figure 5-38 illustrates the configuration likely to occur during intersection collisions. The impacted vehicle, vehicle #1, is entering the roadway at some angle θ and because of this maneuver, will be at a relatively low speed (under 15 mph). Consider the intersection situation depicted in Figure 5-39. The situation occurs when vehicle #1 makes a legal left turn into the roadway occupied by vehicle #2. To determine the probable speed of vehicle #1 during this turning maneuver, the following assumptions are made:

- Turning radius, R = 40 ft
- Lateral acceleration comfort limit = .2 g's

ASSUMPTIONS:

$V_2 = 0 - 35$ MPH*

$V_1 = 0 - 11$ MPH**

* 35 MPH SPEED LIMIT COMMON FOR MUNICIPAL STREETS

** COMMON SPEED RANGE FOR TURNING MANEUVERS

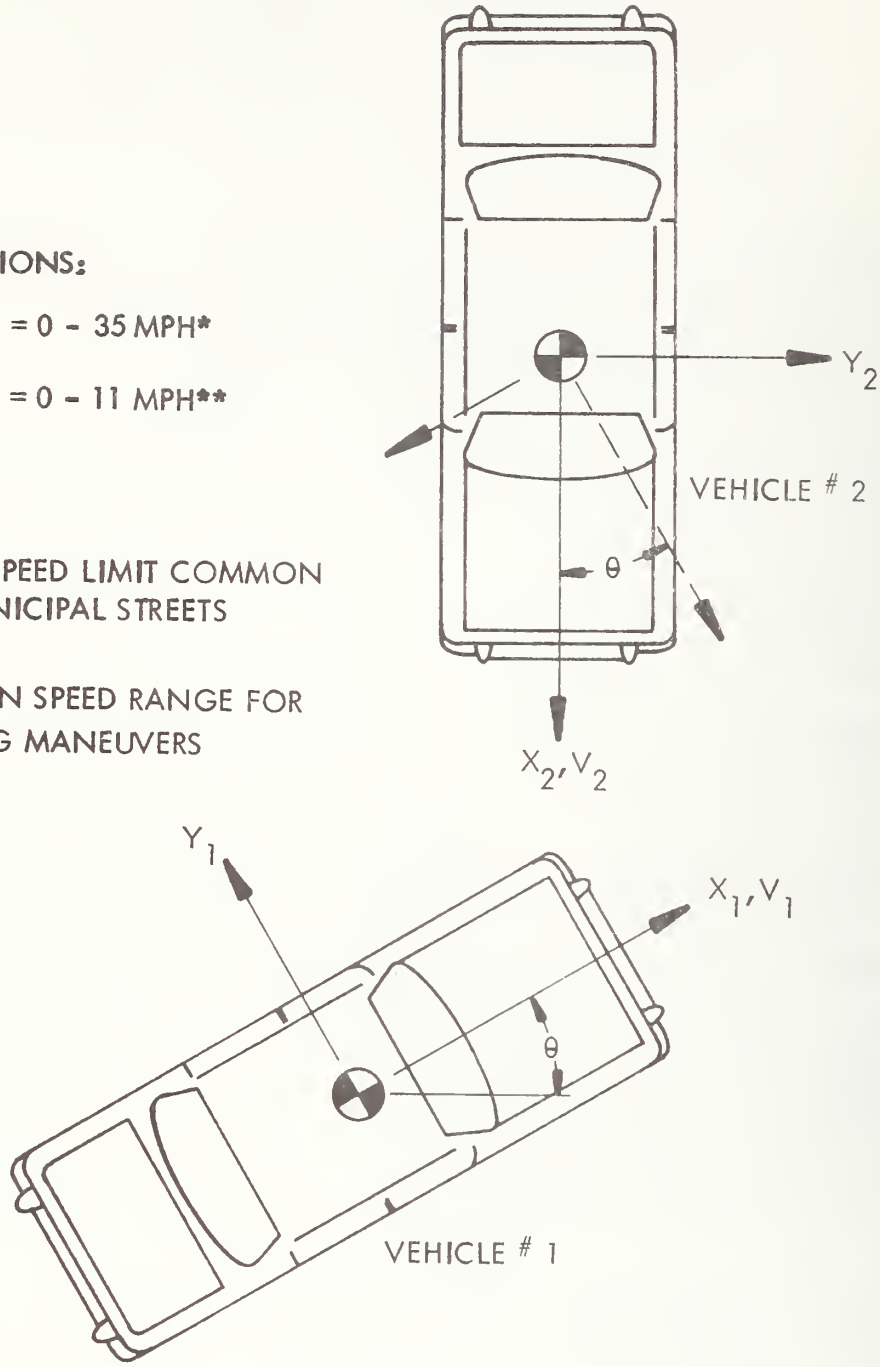


Figure 5-38. Configuration for Oblique Intersection Collisions

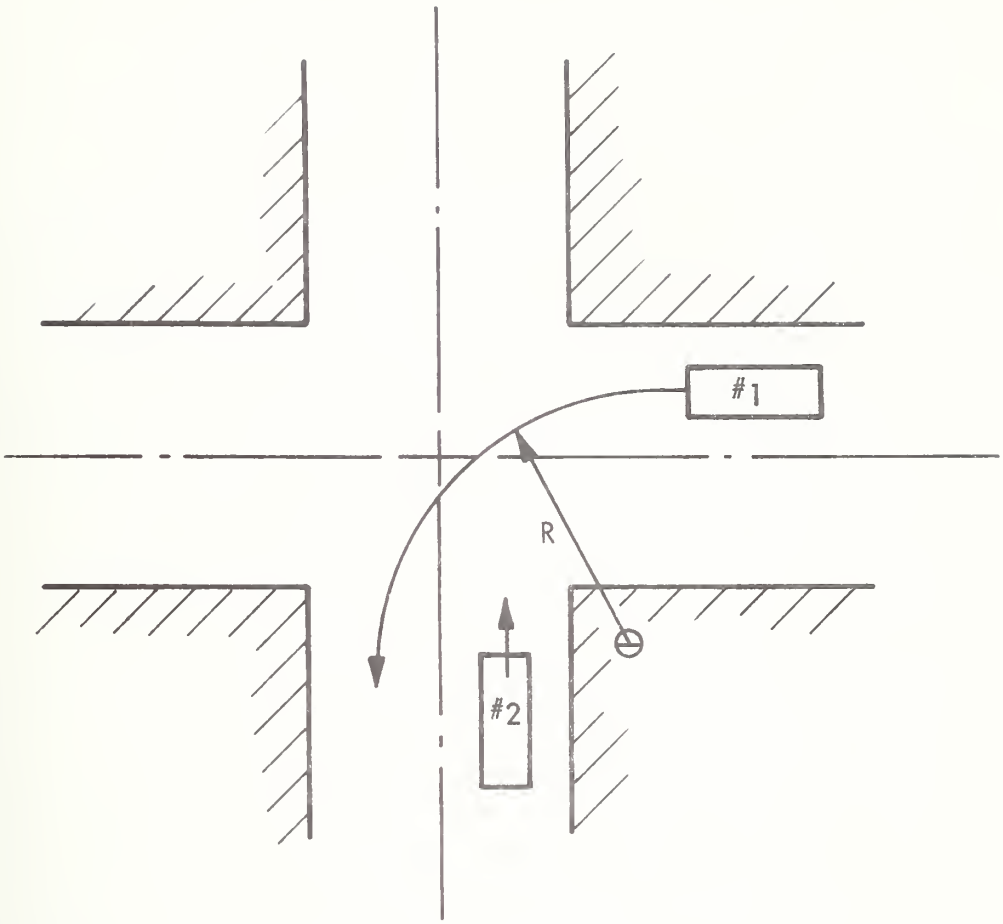


Figure 5-39. Intersection Collision Configuration

With these assumptions, the maneuvering speed of vehicle #1 can be determined as follows:

$$V_{LIMIT} = \sqrt{R \cdot a_{comfort}} = 1.730\sqrt{40} = 10.9 \text{ mph}$$

A reasonable assumption for the striking vehicle, vehicle #2, is that its traveling speed will be near 35 mph, the speed limit commonly found for municipal roadways involving intersections. By resolving the velocity vector for the striking vehicle into the longitudinal and lateral axis of the impacted vehicle (see Figure 5-38), the following relative impact speeds for various angles are derived:

Angle, θ	Lateral Relative Speed, mph	Longitudinal Relative Impact Speed, mph	Resultant mph
0	35	11	36.7
30	30.3	28.5	41.6
45	24.7	35.7	43.4
60	17.5	41.3	44.8
90	0	46	46.0

From the standpoint of energy absorption requirements for the impacted vehicle in the lateral and longitudinal directions, it does not appear that the above configurations represent as severe a requirement as for the "normal" impact modes previously discussed. However, what is not indicated here is the response of the crash victim(s) to the resultant acceleration of the corresponding vehicles. The impacted vehicle occupant, for example, will receive an appreciable lateral acceleration as well as a longitudinal acceleration with an unknown resulting injury severity. It is possible that this impact configuration may be non-critical from a vehicle crush standpoint, but highly critical from an occupant response standpoint due to lessened restraint effectiveness resulting from the obliqueness of the

impact. To evaluate this possibility, the MDAI accident data were used to evaluate the effect of impact obliquity on injury severity distribution. The results are summarized in Table 5-18. The results show that for the oblique frontal category, previously categorized as low speed intersection collisions, the injury severity distribution is approximately the same as for the frontal category with its characteristically high impact speeds. On the other hand, a comparison of the injury severity distributions for oblique frontal and side impacts shows that side impacts (also characterized as low speed impacts) have a much more severe injury distribution. Consequently, it can be deduced that oblique frontal impacts are not as severe as the "normal" side impact configurations, but are comparable in severity to frontal impact configuration with characteristically higher impact speeds.

For rear impacts, Table 5-18 indicates that these impacts are considerably less severe than frontal or side impacts. Oblique rear impacts appear to be slightly more severe than colinear rear impacts but considerably less severe than orthogonal side impacts.

It appears, therefore, from the MDAI data that obliquity in impacts, especially frontal impacts, can have a detrimental effect on the occupant injury severity and consequently, careful consideration must be given to the RSV restraint design for these much more frequently occurring impact configurations. This serves as justification for the proposed oblique impact design conditions in specification Figure VIII.

Other oblique impact configurations which may have an influence on vehicle design are the sideswipes shown in Figure 5-37c. These impact conditions can involve high impact speeds, a characteristic of head-on collisions. A limiting condition for this impact mode is the normal ($\theta = 90°$) front-side impacts which are characteristic of low speed intersection collisions. This limit configuration has been previously treated. The other extreme is the shallow angle ($\theta \rightarrow 0$) impact resulting in a glancing blow to the impacted vehicle. In the cited study by Grime and

Table 5-18 Effects of Impact Direction on Injury Severity

DIRECTION	NO INJURIES (00,01)	INJURIES			FATALITIES (06-10)	TOTALS
		MINOR (02)	MODERATE (03,04)	SEVERE (05)		
FRONT 12	2026 (70.9)	408 (14.3)	251 (8.8)	30 (1.0)	143 (5.0)	2858 (100)
OBLIQUE FRONT 01,11	2019 (70.2)	448 (15.5)	236 (8.2)	35 (1.2)	137 (4.7)	2875 (100)
SIDE 02-04,08-11	1754 (65.5)	388 (14.4)	272 (10.16)	54 (2.0)	219 (8.1)	2678 (100)
OBLIQUE REAR 05,07	181 (76.7)	30 (12.7)	11 (4.7)	1 (.4)	13 (5.5)	236
REAR 06	449 (80.3)	92 (16.5)	11 (2.0)	1 (.2)	6 (1.0)	559
						9215

Jones, it was determined that for this impact configuration, the impacted vehicle moves very little (from its original path) during impact with characteristically low resulting accelerations. However, a potential exists for excessive side crush due to the front corner of the striking vehicle traversing the surface of the side structure of the impacted vehicle. This action can set up a traveling crush zone (traveling at the relative impact speed) which, when reaching the vicinity of an occupant, can impart sudden localized acceleration to parts of the occupant's body. To alleviate this potential problem, it is necessary to limit the lateral crush load of a vehicle front structure so that it is compatible with an RSV side structure in a side-swipe impact configuration. A lateral crush load limit of 60 kips (20 g lateral acceleration limit for RSV side structure) is therefore imposed.

2.4.2 Exterior Protection

In considering the rising cost of automotive repairs, some level of damage-free protection seems to be warranted. This damage-free protection is seen to be applicable primarily to the low speed, semi-trivial collisions encountered in parking lots or other congested areas where low speed traveling is encountered.

As a minimum, both front and rear exterior protection systems shall be provided, both capable of sustaining pendulum collision tests of 5 mph per FMVSS 215 as well as barrier collision tests of 5 mph.

2.4.3 Fuel System Integrity

The fuel system or energy source shall be located away from the primary crush zones so that penetration or rupture of the fuel tanks and connecting lines or release of fuel from these components will not result when the vehicle is subjected to any of the design impact modes. Release of fuel from the engine shall be limited to the minimum amount practicable for the engine design.

Justification for this performance specification is not required since there are no apparent significant design penalties resulting from this requirement.

2.4.4 Pedestrian/Cyclist Protection

Of all the possible passenger vehicle accident modes considered in this study, the pedestrian/cyclist accident mode stands out as the greatest threat to a crash victim. This is evident from the data developed in the societal cost study (see Section 3.3, Volume II) which shows the following average societal cost per incident for each of the six crash modes considered:

Impact Mode	Total Societal Cost, All Injuries $ Billions	Number of Injuries & Fatalities	Average Cost/Incident
Vehicle-vehicle	18.6	2.391×10^6	$ 7,790
Vehicle-pedestrian	4.5	1.778×10^5	25,309
Vehicle-fixed object	5.1	3.678×10^5	13,866
Rollover	1.7	7.638×10^4	22,259
Vehicle-pedalcycle	1.1	6.047×10^4	18,191
Vehicle-motorcycle	1.9	6.981×10^4	27,217

The data shows that the average pedestrian/cyclist injury severity (reflected as a societal cost) is significantly greater than the remaining accident modes. Fortunately, the frequency of occurrence of these accident modes is quite low when compared to the less severe vehicle-vehicle accident mode.

Data from the societal cost study, Section 3.3, Volume II, shows the following societal cost distribution for the pedestrian and cyclist impact modes with regard to impact direction:

Accident Mode	Impact Direction	Societal Cost $ Billions
Vehicle-pedestrian	Front	4.1
	Side	.2
	Rear	.2
Pedalcycle	Front	.9
	Side	.2
	Rear	.1
Motorcycle	Front	1.1
	Side	.7
	Rear	.1
TOTAL		7.6

It is apparent from this data that frontal impacts, representing over 80% of the associated societal costs, is the major contributor to injuries and fatalities for the pedestrian and cyclist impact modes. These frontal impacts represent approximately 14% of the societal cost associated with all vehicle frontal collsiions. This significant representation of societal costs serves as justification for introducing a design standard to help reduce the severity of this impact mode.

A research study by Tharp revealed that there is a strong, statistical [5
linear relationship between injury severity and impact speed. This statistical relationship was found to be the strongest for direct impacts (does not include glancing or low speed crushing blows). Furthermore, it was shown that secondary impacts of the crash victim into environmental objects are statistically less severe than a direct vehicle impact. This is especially true for high speed impacts since only a fraction of the potential energy is transferred to the victim during a glancing or grazing blow, and is subsequently dissipated through the interaction of the victim with environmental objects (roadway, shrubs, parked cars, etc.). This observation led to a recommendation in that study that the front structure of a vehicle be designed to deflect a struck object so that it develops a glancing blow rather than a

direct impact. The referenced study further shows that fatalities resulting from a direct impact (as opposed to a puncturing blow or a low speed crushing blow) seldom occur at speeds less than 20 mph. At speeds in excess of 20 mph, fatal injuries from fractured necks and spines and crushed pelvis appear. At impact speeds in excess of 40 mph, an increasing number of fatal multiple internal injuries appear. Fro these higher impact speeds, vehicle "shaping" appears to be the only recourse in crashworthy design.

Research work done by Peugot-Renault indicate the feasibility of using pedestrian retention devices to control the kinematics and retain the crash victim on the hood of the striking vehicle during low speed (under 20 mph) impacts. This concept was based on the premise that it is more favorable for the victim to "ride" the striking vehicle rather than being deflected away. [60]

The accident projections for the 1985 time frame show significant number of injuries and fatalities from pedestrian impacts in the moderate (20-30 mph) and severe (30-40) impact speed ranges. For this environment, the device proposed by Peugot-Renault may prove to be beneficial at the low impact speed range (under 20 mph) but could add potential hazards at the higher impact speed ranges due to entangling or striking the victim with the device once it is triggered. Other basic questions pertaining to retention devices remain to be answered: What are the consequences of inadvertent actuation or failure to actuate when needed? What is the compatibility of the device with other systems in production vehicles? etc.

For this specification, vehicle"shaping" to control the kinematics of the victim coupled with forgiving surfaces constitute the minimum requirements. Only when it can be shown that retention devices do not introduce added hazards at the higher impact speeds and the basic problems cited can be overcome will such devices be considered.

Several technical problems are anticipated in crash test verifications of the pedestrian impact mode and these may preclude the possibility of conducting any near-term full-scale impact test verification

program. Current shortcomings in demonstrating realistic kinematic response of dummies in interior impacts will be amplified significantly when attempting to utilize similar measuring devices for exterior impact simulations. Therefore, it is recommended that certifications of this mode be limited to measurements of the vehicle geometry and energy absorbing capabilities pending the development of dummies having required characteristics and the associated instrumentation.

The pedalcycle (bicycle) and motorcycle impact modes present additional problems in vehicle crashworthiness design. These problems stem from: (a) the higher location of the victim prior to impact (relative to most pedestrian impacts), and (b) the significantly higher speed at which the victim is traveling prior to impact. Both factors increase the probability for the victim to impact the more hazardous structure surrounding the front windshield. It is concluded, as it was for pedestrian impacts, that any attempt to provide positive control to the cyclist during impact will be futile. Therefore, the proposed design approach for cyclist protection will be identical to that proposed for pedestrian protection and will consist primarily of: (1) properly shaping the vehicle front structure, and (2) providing forgiving surfaces for areas likely to be contacted by the victim during impact where feasible.

Audio/Visual Signaling. The guideline requirement for an audible signal to be automatically activated when the vehicle is put into reverse has been deleted. The implicit intent of such a signal is to warn pedestrians behind the car of its impending movement.

Estimates of pedestrian accidents involving backing up range from [59,61] 1.7 to 3.5 percent of all pedestrian accidents. While this range indicates a small incidence of such accidents, the back-up alarm, if effective, would probably involve an equally small cost and weight penalty. However, an overriding consideration may be the potential nuisance effect

the automatic alarm would have in crowded parking lots, in underground garages, at night in residential areas, etc. Since the effectiveness of such an alarm has not been demonstrated nor is the public's acceptance of its purpose known, this signal has not been specified.

2.5 OCCUPANT COMPARTMENT SYSTEMS

The occupant compartment represents one of the most critical areas in passenger vehicle crashworthiness design, for it's here where the occupant/vehicle interaction occurs during the more frequent accident modes. The major occupant protection systems comprising the occupant compartment are:

- Seating systems
- Occupant restraint systems
- Interior crash attenuation devices (crash padding, energy absorbing steering column, etc.)

The primary objective of the performance requirements for these systems is to de-hostilize the interaction of the occupants with the vehicle during impact. These requirements are reflected as maximum levels of pressure, load and accelerations imparted to the victim(s) during impact which are consistent with human tolerance levels determined by bio-medical research. To facilitate an effective design standard for the vehicle interior, it is important to identify those components most frequently encountered by the occupant during impact and which contribute significantly to injuries.

A number of research studies have been conducted to date to [62]
investigate the sources of injuries resulting from occupant contact with [63]
the vehicle interior. The results from a study by Joksch and Wuerdemann, [64]
summarized in Table 5-14, show the relative contributions of various interior components to several levels of injury severity.

Table 5-19

Distribution of Injuries by Interior Components
Most Frequently Struck

Source of Injury	Degree of Injury						Relative Contribution of Source to:		
	Minor	Non-Dangerous	Dangerous	Fatal	Degree Not Reported	Any Injury	Any Injury (%)	Fatal Injuries (%)	Fatal & Dangerous Injuries (%)
1. Instrument Panel	3,182	984	109	85	247	4,608	23	11	11
2. Steering Wheel Assembly	2,461	960	199	133	387	4,140	21	18	19
3. Windshield	1,842	599	92	84	326	2,943	15	11	10
4. Door Structures	1,586	544	75	62	151	2,418	12	8	8
5. Ejection	858	599	337	278	144	2,216	11	37	36
6. Backrest of Front Seat (Top)	597	187	40	9	107	940	5	1	3
7. Top Structures	448	120	49	48	117	782	4	6	6
8. Backrest of Front Seat (Lower)	533	134	18	1	40	726	4	Negl.	1
9. Front Corner Post	240	122	34	51	49	496	3	7	5
10. Rear View Mirror	327	87	8	7	51	480	2	1	1
TOTALS	12,074	4,336	961	759	1,619	19,749	100	100	100
Degree of Injury as Percent of Any Injury	61	22	5	4	8	100			

Four components stand out as principal contributors to injuries; these are (ranked in descending order of frequency of occurrence):

- Instrument panel
- Steering wheel assembly
- Windshield
- Door structure

A later study by Cromack, et al, shows a similar ranking of interior [63] components with added dimension of force direction and principal damage areas. These results are summarized in Tables 5-20 and 5-21.

Table 5-20

Injury-Producing Components by Force Direction

	Force Direction, O'Clock			
Component	(11,12,1)	(2,3,4)	(5,6,7)	(8,9,10)
Instrument Panel	30	28	26	24
Steering Assembly	26	17	19	22
Windshield	18	12	0	10
Object Exterior to Car	4	4	5	2
Outside Surface of Car	2	1	0	0
Surface of Side Interior	4	12	9	16
Back of Seats	4	3	19	3
Other	12	22	23	23

Table 5-21

Injury-Producing Components by Damage Area

	Damage Area			
Component	Front	Back	Left	Right
Instrument Panel	29	24	20	21
Steering Assembly	24	10	17	15
Windshield	16	10	8	8
Object Exterior to Car	8	0	10	17
Outside Surface of Car	6	0	5	3
Surface of Side Interior	3	7	15	11
Back of Seats	3	23	3	2
Other	11	26	22	23

A point of interest reflected in the results of Cromack's study is that a significant percentage of injuries resulting from side or rear impacts are apparently caused by the instrument panel and/or steering assembly, possibly indicating the effects of rebound from the seat back and/or side structures. In establishing the performance requirements for the occupant compartment systems, care must be taken not to overlook the effects of secondary impacts by the victims within the passenger compartment. This requires the vehicle interior to be treated as a total system in which all components (e.g., seats, restraint, interior padding) work together to form an effective occupant restraint.

These considerations and those discussed in the subsections that follow result in performance specifications which are essentially the same as those in the guidelines.

2.5.1 Seating Systems

The seating systems of a passenger vehicle probably interface more with an occupant than any other interior component and consequently merit separate consideration in the interior crashworthiness design. Since the seating systems are likely to significantly influence the kinematic behavior of an occupant during impact, it is important that these systems be designed to complement rather than negate the performance of other crash mitigating devices (i.e., restraints, crash padding, steering assembly, etc.). The proposed RSV design specifications for the protective characteristics of the seating systems were previously provided in specification Table III. The justification for this specification is based on the fact that the proposed specification provides more protection than currently specified in FMVSS 208 and is consistent with previous ESV work which has proven its feasibility. Table 5-22 provides a comparison between the RSV seat protection requirements proposed herein with requirements for the current FMVSS 208 and previous ESV work.

Table 5-22

Comparison of RSV, OESV, and ESV Requirements and Specifications for Seating Systems Without Functional Restraint Devices in Rear Impacts

	Specification			
	FMVSS 208	RSV	OESV	ESV
Impact Speed	--	40 mph[a]	50 mph[a]	50 mph[b]
Head Acceleration (P-A)	--	HIC 1000[e]	SI 1000[d]	80 g/3 mse
Chest Acceleration (P-A)	--	60 g/3 msec	60 g/3 msec	40 g/3 mse
Pelvic Acceleration (P-A)	--	--	--	40 g/3 mse
Head Rotation	--	60°	--	--

[a] Car-Car Impacts

[b] Car-Moving Barrier (rigid, 4000 lb)

[c] Design Goals

[d] Per SAE J885a, October 1966

[e] $$HIC = \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a\,dt \right]^{2.5} (t_2 - t_1)$$

2.5.2 Occupant Restraint Systems

Much research has been conducted to date to determine the effectiveness of occupant restraints. Although some disagreement currently exist as to the most effective type of restraint (e.g., active or passive belts vs passive inflatable systems), general agreement has been reached with regard to the importance of a restraint system in mitigating the effects of a collision on the occupant(s).

The intent of this section is not to resolve the issue regarding the most effective type of restraint system (this is the subject matter for Phase II), but rather to demonstrate whether or not acceptable levels of protection can be offered to RSV occupants for the specified impact configurations and vehicle dynamic response characteristics (acceleration signature). The description of the analytical evaluations used in this determination follow.

Restraint Evaluation Methodology. The evaluation methodology consists of the following steps:

- Define the restraint configuration to be evaluated.
- Define the minimum performance criteria to be satisfied.
- Simulate the articulated response of crash victim during impact.
- Evaluate the injury threat to victim based on established criteria.
- Reiterate the above steps until maximum protection is achieved and evaluate the resulting restraint performance.

Restraint Configurations. As noted in the RSV characterization study, Section 4.2.3, the following general restraint types are recognized:

- Passive deployable restraint
- Passive deployable restraint and lap belt
- Passive torso and/or lap belt restraint
- Active torso and/or lap belt restraint

- Passive torso belt, passive knee restraint
- Active torso belt, passive knee restraint

With the assumption that active and passive belts can be designed to provide the same optimum restraint characteristics and recognizing that seat belts alone do not provide ample protection for the design impact speeds proposed for the RSV, the restraint candidates for evaluation reduce to the following:

- Passive deployable restraint
- Passive deployable restraint and lap belt
- Passive/active torso and lap belt restraint
- Passive/active torso belt, passive knee restraint

In keeping with the intent of previous ESV work and the current RSV effort, it is deemed necessary that a passive restraint system be provided for at least the RSV front seating positions to maximize societal benefits. A NHTSA staff report indicates that, in general, the injury severity of [65 rear seating victims is significantly less than that of a front seated occupant. This coupled with a low occupancy rate for the rear seats suggest that an active system could be cost effective for rear seat use. It is noted that the second concept listed above, passive deployable restraint and lap belt, cannot (without objectionable penalties) be easily converted to a complete passive system; therefore, it was eliminated from further consideration.

Restraint Performance Criteria. Restraint performance cannot be evaluated until desired restraint performance characteristics (performance criteria) are established. In general, the desired characteristic of an RSV restraint system is to provide a maximum level of protection consistent with the current state of the art. The proposed level of protection for the RSV occupants is the same as the guideline requirements proposed by

DOT except the impact speed requirements have been reduced to reflect benefit/cost considerations. The proposed RSV restraint performance specification is compared with the current FMVSS 208 requirements as well as with performance requirements for previous ESV work in Table 5-23. Obviously, the proposed RSV requirements are much more stringent than current standards but are considered to be within the current state of the art as evidenced by the findings of prior ESV programs and of other research programs on restraint systems.

Occupant Restraint Simulations. Computer simulations were made to evaluate the occupant kinematics during impact and to evaluate the resulting levels of protection attainable with the various candidate restraint systems.

The computer model used for this evaluation is illustrated in Figure 5-40. This model was developed by AMF in a previous research [66] effort and has subsequently been verified by the test data. The crash victim response model is basically planar, consisting of three mass elements (representing the head, torso and upper thighs) hinged to provide articulation at the hip and neck pivot points. Non-linear spring elements are introduced to represent neck muscular tone, chin/sternum impact, torso, knee (or hip) and head restraint characteristics. The model has the capability of determining as a function of time, the following responses:

- HSI (head severity index) directly
- HIC (head injury criteria) indirectly
- Torso accelerations
- Head accelerations
- Pelvic accelerations
- Femur loads

Table 5-23. Comparison of ESV, OESV, RSV Requirements and Specifications

Occupant Protection: With Functional Device

Note: ESV specs as modified during the program.
Note: G_R is resultant G level.

Specification	FMVSS 208	ESV	OESV	RSV	Comments
FRONTAL CRASH					
Impact Velocity (Equivalent Barrier)	30 mph	50 mph	45 mph	45 mph ± 15°	
Impact Angle	0°	± 15°	To ± 45°, vel. dec. linearly to 30 mph	~25 mph, to ± 45°	45° barrier impact at 30 mph a difficult design case for most deployable restraint systems.
Head Acceleration	HIC 1000	80 G_R/3 msec	SI 1000	HIC 1000	Requirement less severe in most cases with HIC.
Chest Acceleration	60 G_R/3 msec	60 G_R	60 G_R/3 msec	60 G_R/3 msec max. 1500 G/sec onset rate (a,b)	A difficult goal to achieve with belts preloaded or low elongation. Easier with air bags.
Femur Force	1700 lb	1400 lb	1400 lb	1700 lb	
Load Distribution	--			Maximize (a)	A significant goal. Study shows best distribution with current harness systems ~25%; inflatable belts ~35%; air bags ~90%.
Voluntary Action	Optional				
Front		None	None	None	RSV requires study of relative cost merits of alternate systems.
Rear		None	-	-	
Hazards	-	-	None	None	Air bag hazards (overpressure, noise) still remain.
Reliability	-	-	High	High	
ROLLOVER CRASH					
Impact Velocity	30 mph	2 ft drop	30 mph (c)	30 mph (c)	
Head Force		15 G/3 msec	SI 1000	HIC 1000	
Chest Force	Containment	15 G/3 msec	G_R 60/3 msec	20 G/3 msec	
Pelvis Force	Only	15 G/3 msec	-	-	

(a) Goal.

(b) G level change of 20 g or more, upper G level sustained up to 10 msec.

(c) From dolly at lateral velocity at 30 mph.

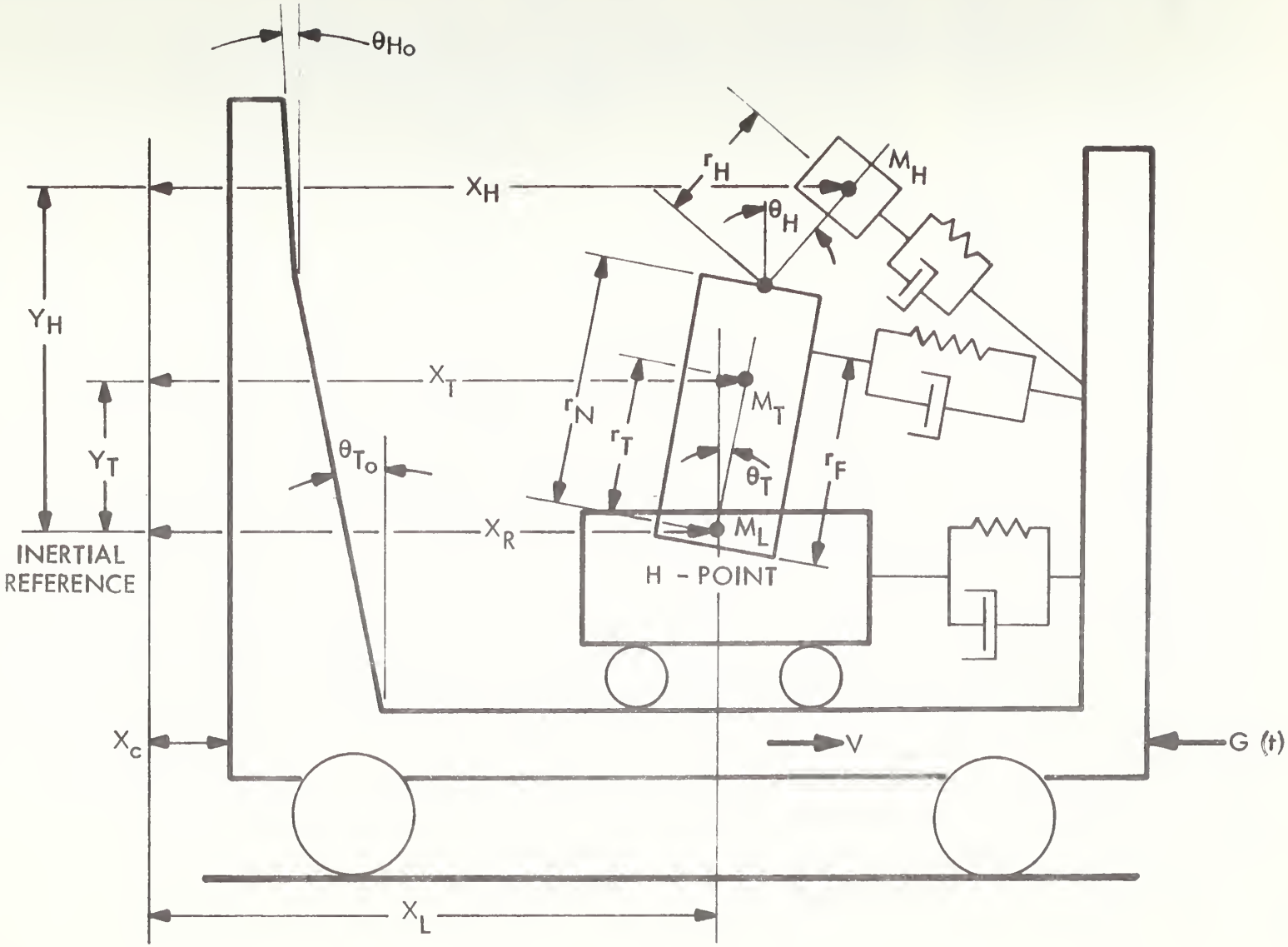


Figure 5-40 Mathematical Model of an Occupant Restraint Encounter

For this investigation, the HSI measurement was used as an indicator for head injury potential rather than the HIC measurement (currently accepted as the standard) to facilitate the many computer runs required for the restraint parametric study effort. HSI is determined directly from the model as indicated above. However, it is to be noted that the HSI parameter was used in a consistent manner for all candidates as a restraint performance indicator and was interpreted in a relative sense to preclude any bias in the evaluation results.

For belt restraint systems, it is a relatively easy task to assign reasonable characteristics for the appropriate spring elements comprising the occupant response model. However, this is not true for a deployable pressurized bag restraint system since the equivalent spring characteristics are functions of bag geometry, venting, gas thermodynamics, occupant staging and other related factors. For this restraint type, a second level of analysis is required to determine the appropriate spring characteristics in the occupant response model. The model, shown in Figure 5-41, was used for this second level of analysis. This model is planar, involving one mass element (representing the effective torso or head mass). Two degrees of freedom are assumed, one translational degree of freedom is assigned to the restraint support, representing vehicle "ride-down". The pressurized bag is assumed to be mass-less and is fully deployed when occupant/restraint encounter occurs. The bag geometry is assumed to be a right circular cylinder with hemispherical end caps. In-flow and venting characteristics can be made arbitrary in the model, but characteristics found in previous restraint optimization work were assumed for this [66] evaluation. The computer program used in this evaluation was initially developed by Cornell and later modified by AMF to include vehicle ride- [67, down and bag pumping during impact. 66]

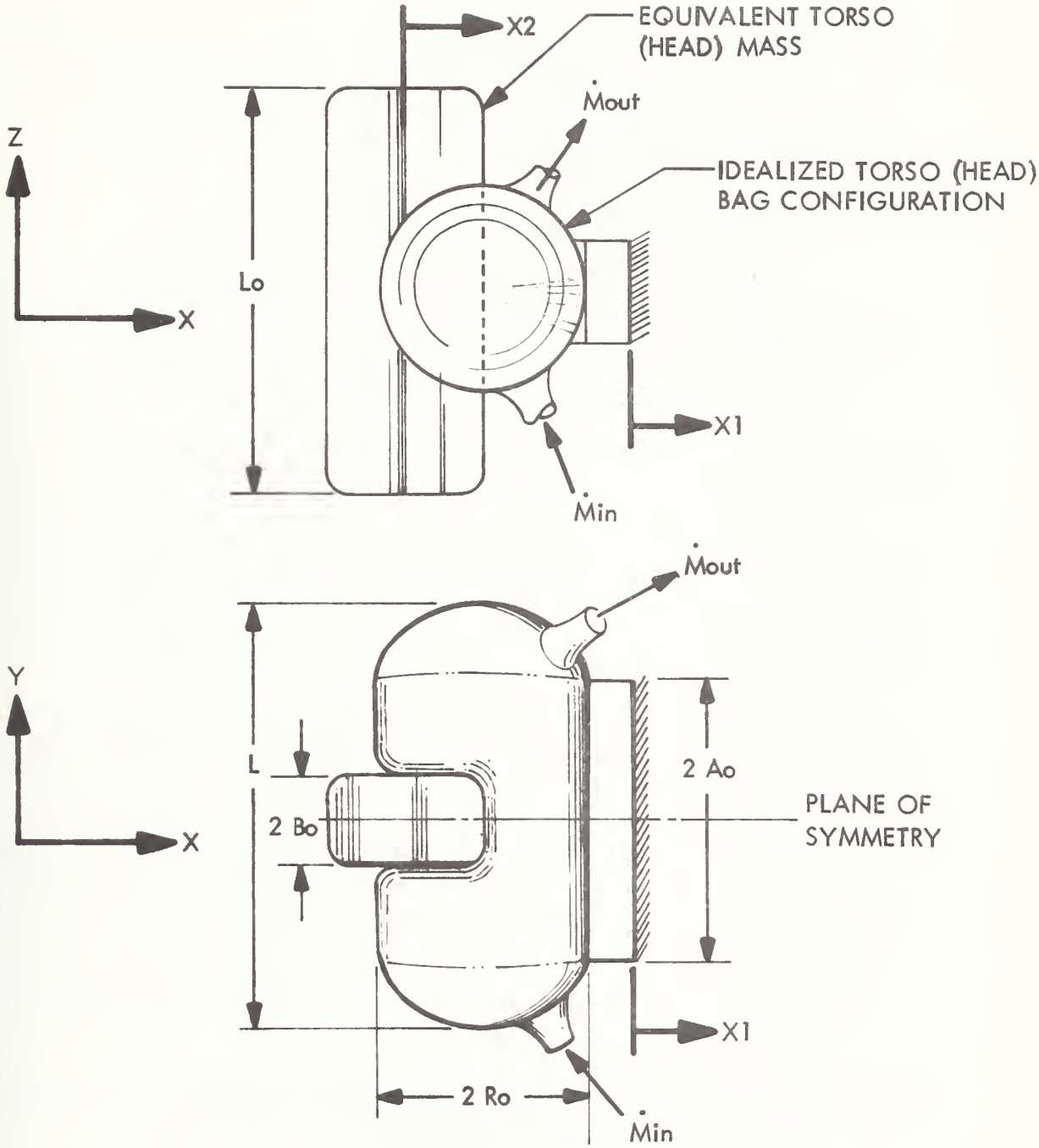


Figure 5-41 Idealized Pressurized Bag Restraint System Model

Restraint Performance Evaluation. Simulations were made using the described methodology and computer models. The assumptions made for, and the results obtained from, these simulations are presented for each candidate system in the subsections that follow.

- Belt Restraint Systems

The belt restraint configuration assumed for this investigation included the following:

- Force limited torso/lap restraint
- Force limited torso/knee restraint
- Force limited pretensioned torso/lap restraint
- Force limited pretensioned torso/knee restraint

Note that in the occupant response model (Figure 5-40) the torso belt knee restraint configuration is the same as the torso/lap belt configuration. Hence, the performance for both configurations is assumed to be identical.

The idealized force deflection characteristics assumed for the force limited belts are shown in Figure 5-42. For this investigation, the slack Δ_o (in Figure 5-42) was assumed zero.

For all simulations, a 50th percentile male occupant was assumed with neck muscular stiffness characteristics consistent with the envelope proposed by Mertz and Patrick. Some adjustment had to be made to the [68] referenced data to accommodate the simple rotational characteristics of the model. However, the same idealized neck characteristics were used for all simulations.

The crash pulse characteristics, shown in Figure 5-43, representing an RSV fixed barrier impact, were used for all simulations.

Simulations were first conducted to "search" for the "optimum" torso and lap belt (or knee restraint) limit loads (see Figure 5-42) for a 50 mph (equivalent barrier) impact condition. The "optimum" limit loads

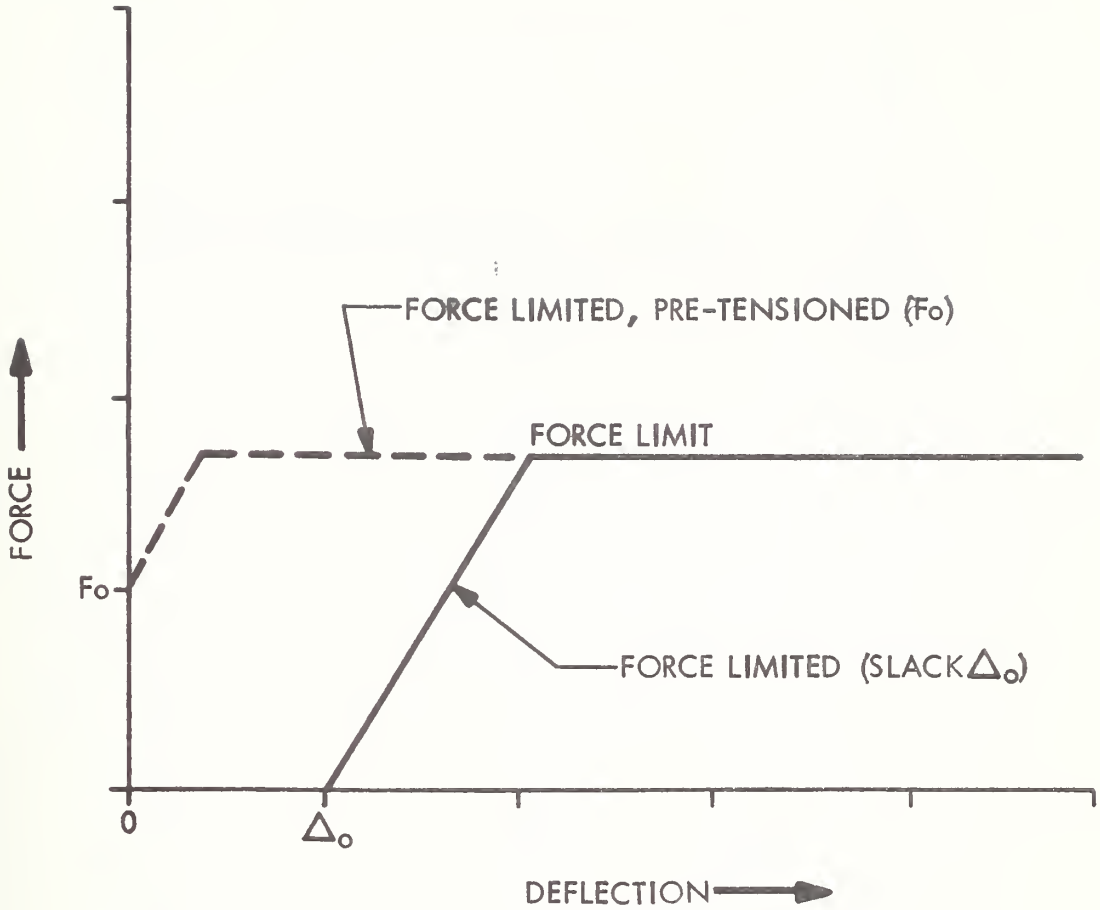


Figure 5-42 Idealized Load Deflection Characteristics for Lap and Shoulder Belts

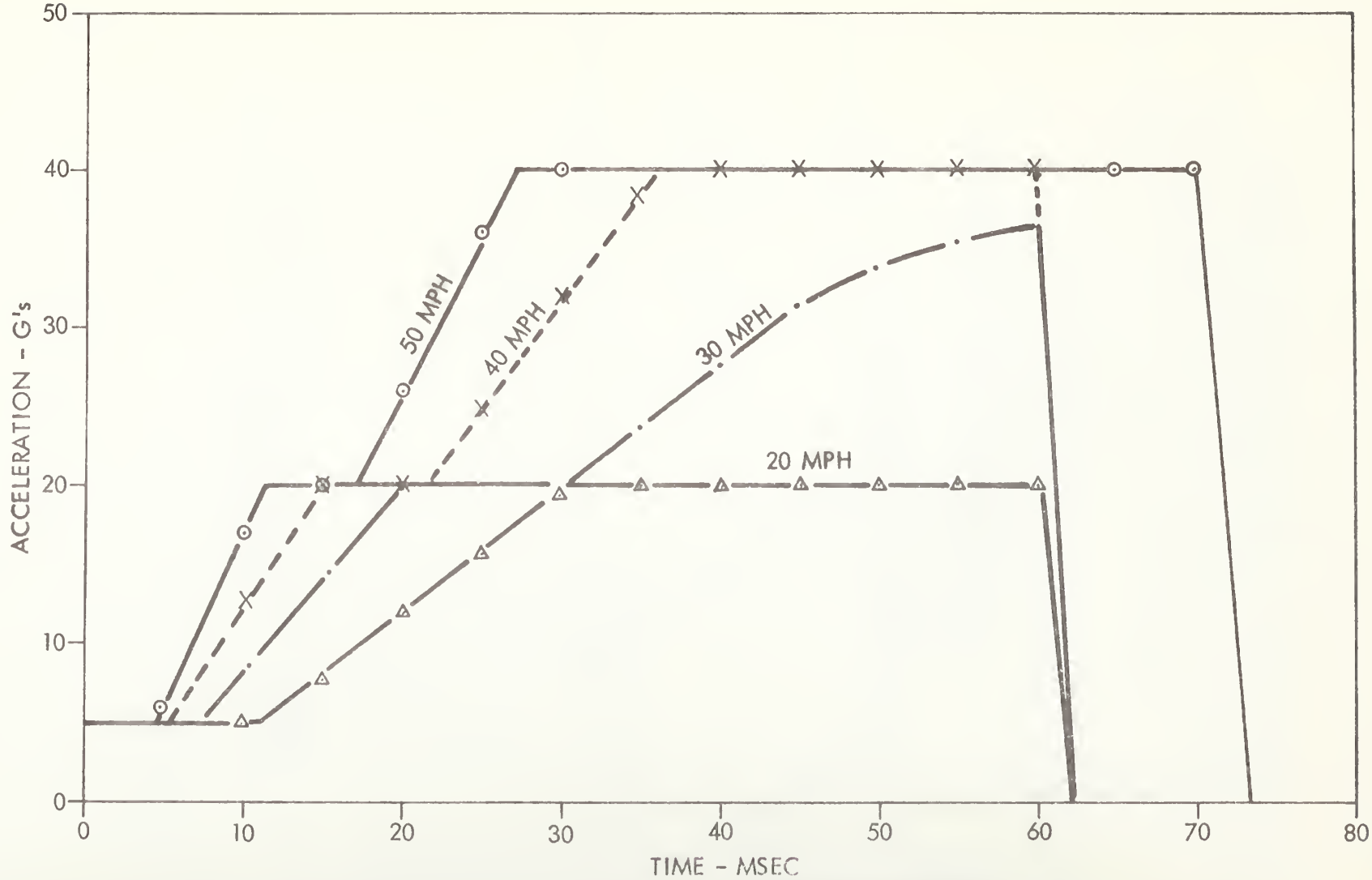


Figure 5-43 RSV - RSV Impact Characteristics

are defined as the load levels resulting with a minimum HSI value while satisfying the criteria for chest acceleration and femur loads (see Table 5-23). With the optimum belt system defined, occupant response simulations were then conducted for lower impact speeds to characterize the restraint system.

The results obtained from the belt restraint simulations are summarized in Figures 5-44 and 5-45. The results indicate that for a 45 mph (equivalent barrier) impact speed condition (which is a frontal impact design requirement proposed for the RSV), both belt restraint concepts satisfy the established HSI and torso accleration limits (see Table 5-23). However, Figure 5-45 shows that adequate head containment requires a pretensioning device. Containment of the hip within the allowable stroking room does not appear to be a problem for either concept.

- Pressurized Bag Restraint Systems

The pressurized bag restraint configuration assumed for this evaluation was an existing system with the following characteristics: [66]

	Torso Bag	Head Bag
Volume	8 ft^3	4.5 ft^3
Diameter	24 in	16 in
Vent area	As required*	As required*
In-flow characteristics	Augmented system	Aspirator system

*Vent area used as a variable in the parametric mode study.

The approach taken to characterize restraint performance consisted of an initial second level analysis described previously, using the model illustrated in Figure 5-40 to determine the load-penetration characteristics of the bag for various impact speeds (all simulations were made

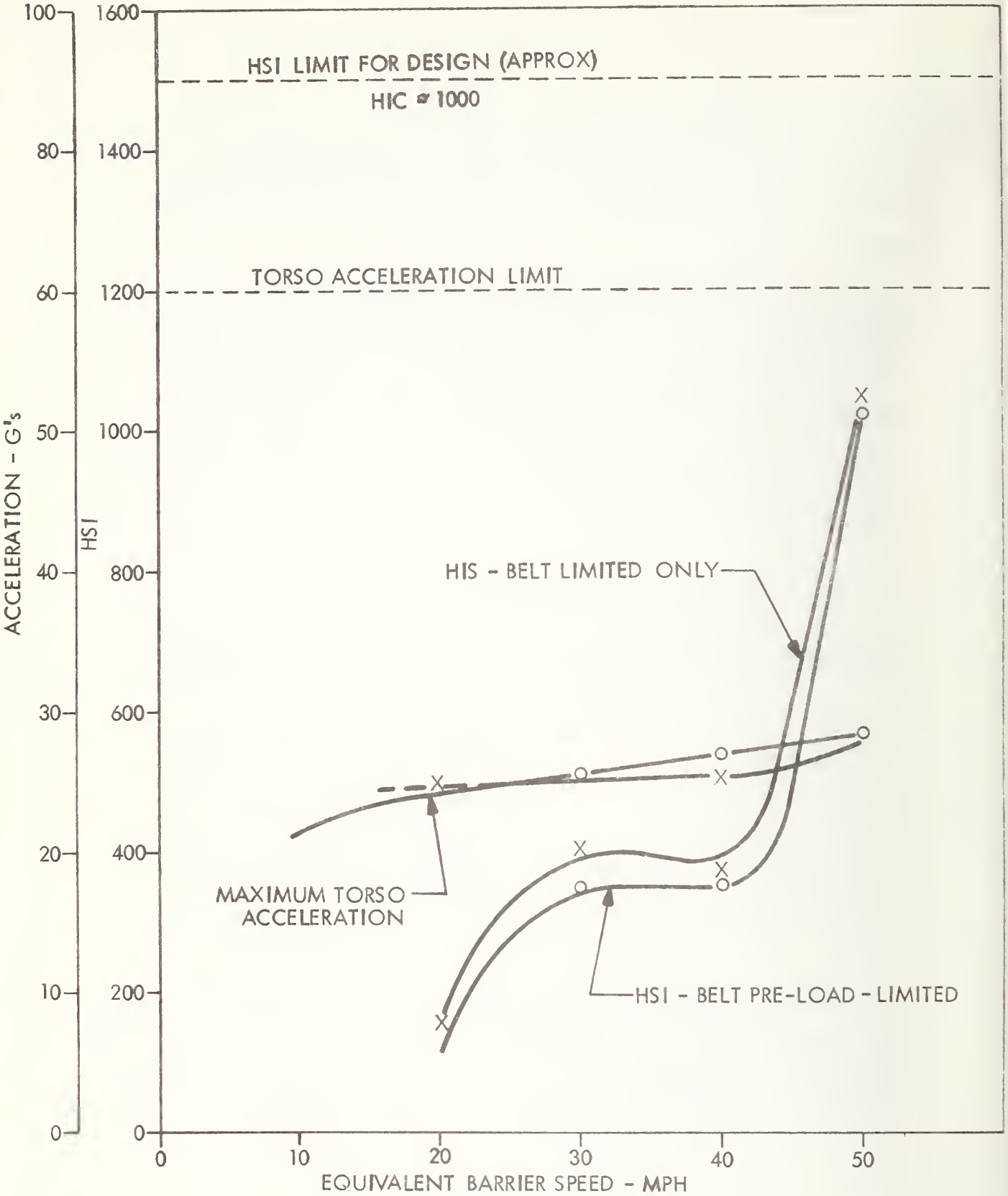


Figure 5-44. Occupant Response Characteristics for Belt Restraint Systems

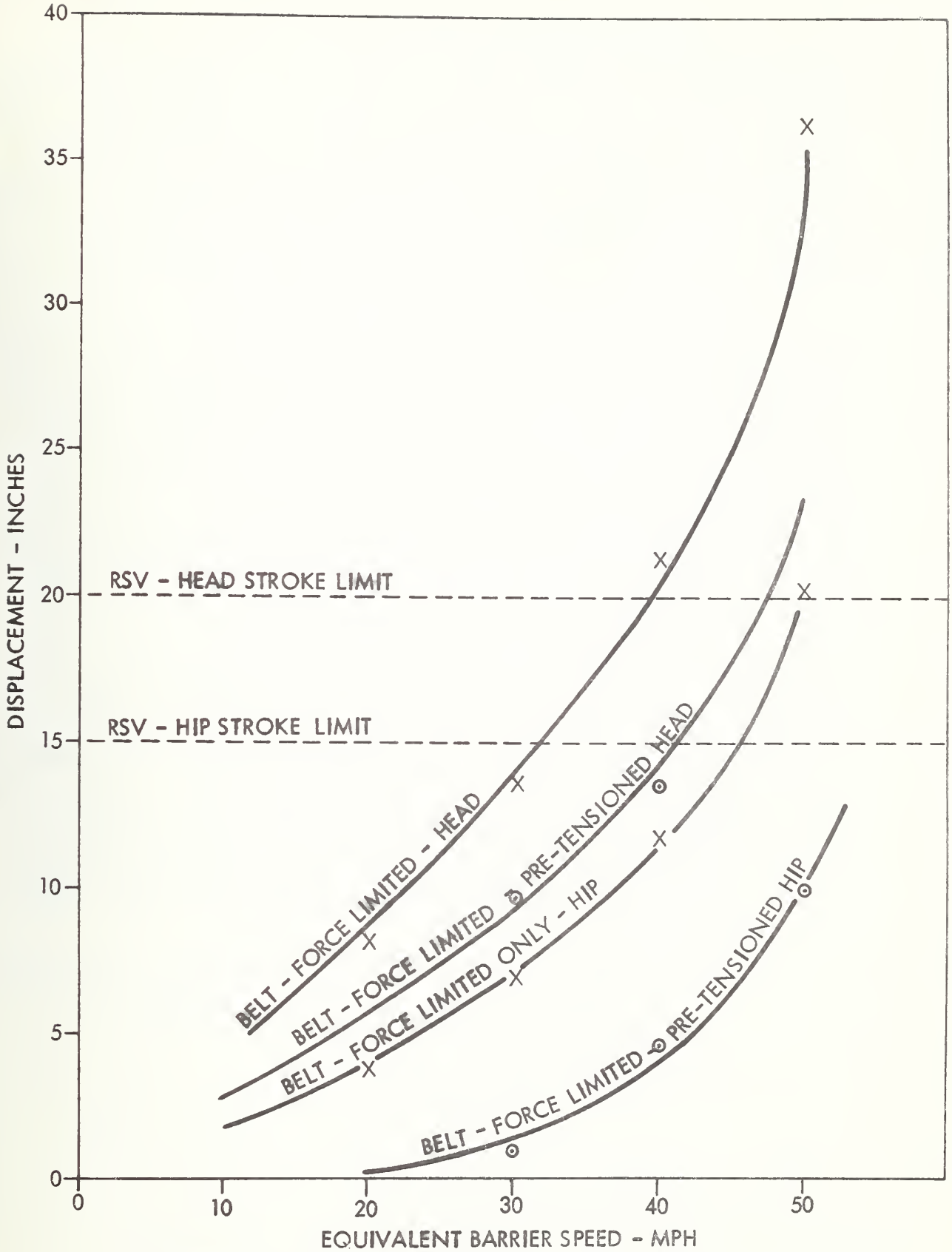


Figure 5-45. Occupant Containment, Belt Restraint Systems

for a 50th percentile adult male). Characteristics determined from this analysis were then used to define the appropriate spring elements in the occupant response model (see Figure 5-40). The articulated motion of the victim was determined using the occupant response model with the bag characteristics previously determined in the bag performance studies. Ideally, plastic characteristics for the knee restraints were also assumed.

The articulated motion of the victim was optimized for each impact speed level by systematically enforcing variations of the various spring characteristics (representing the restraint) until the HSI parameter was minimized and the torso acceleration and femur load limits satisfied. The results of this optimization effort are summarized in Figures 5-46 and 5-47. These figures thus represent the restraint perforce characteristics for a bag system designed with appropriate venting and in-flow characteristics to provide "optimum" restraint performance at all impact speeds. It is apparent that for the restraint system configuration assumed, the established HSI and torso acceleration limits are satisfied for impact speeds to 45 mph (equivalent barrier), a design requirement for the RSV. However, Figure 5-47 indicates a problem with head containment at this impact speed, reflecting the relatively inefficient force-deflection characteristics of the assumed bag system. Several design options, within the current state of the art, appear to be feasible for improving the bag force-penetration characteristics and ensuring adequate occupant containment within the RSV during exposure to the design impact modes. These options include:

- A larger bag or improved shape to increase initial wrap-around.
- A partitioned bag to increase the rate of pressure build-up during impact.
- Increased bag working pressure.

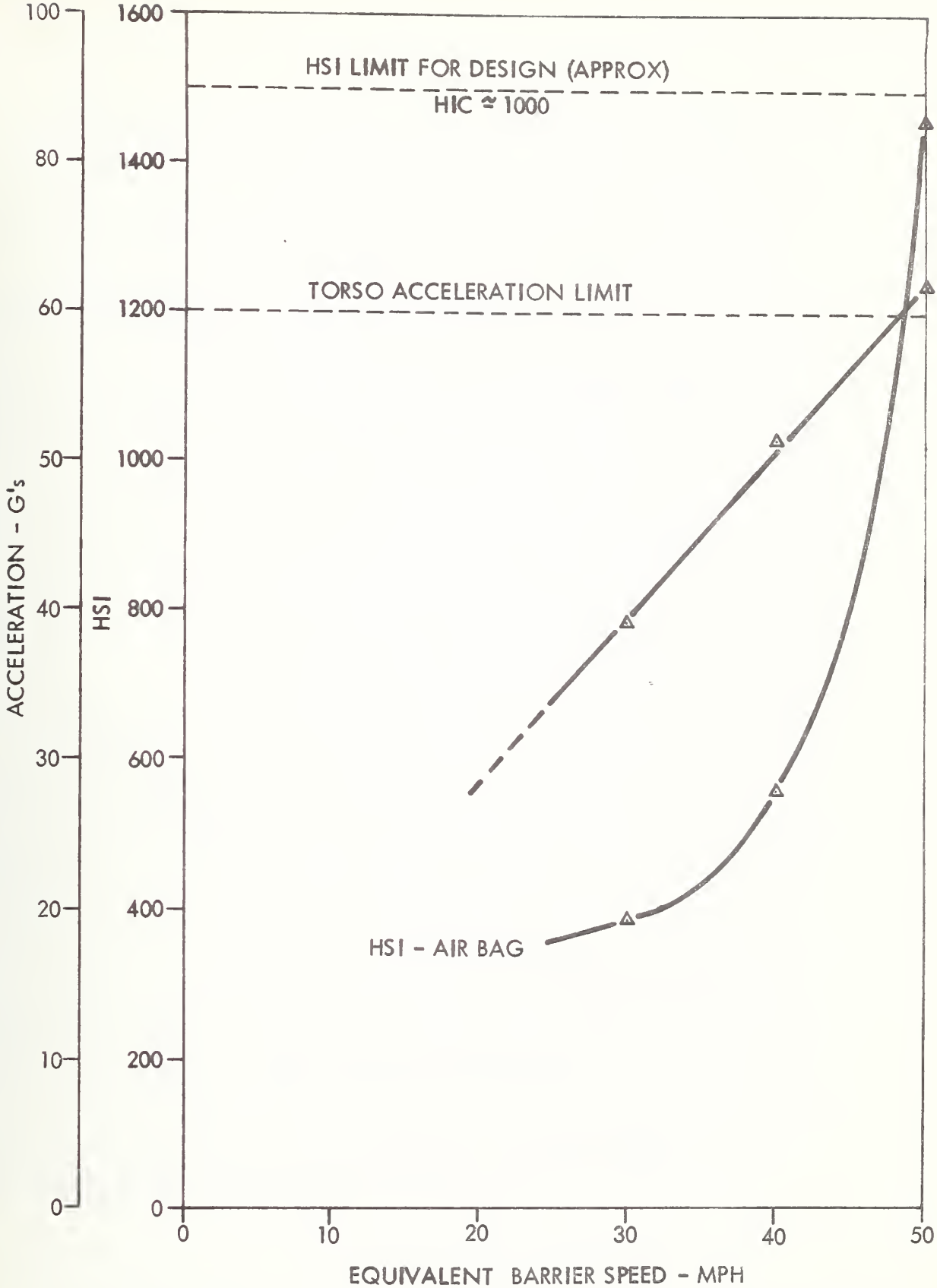


Figure 5-46 Occupant Response Characteristics, Pressurized Bag Restraint

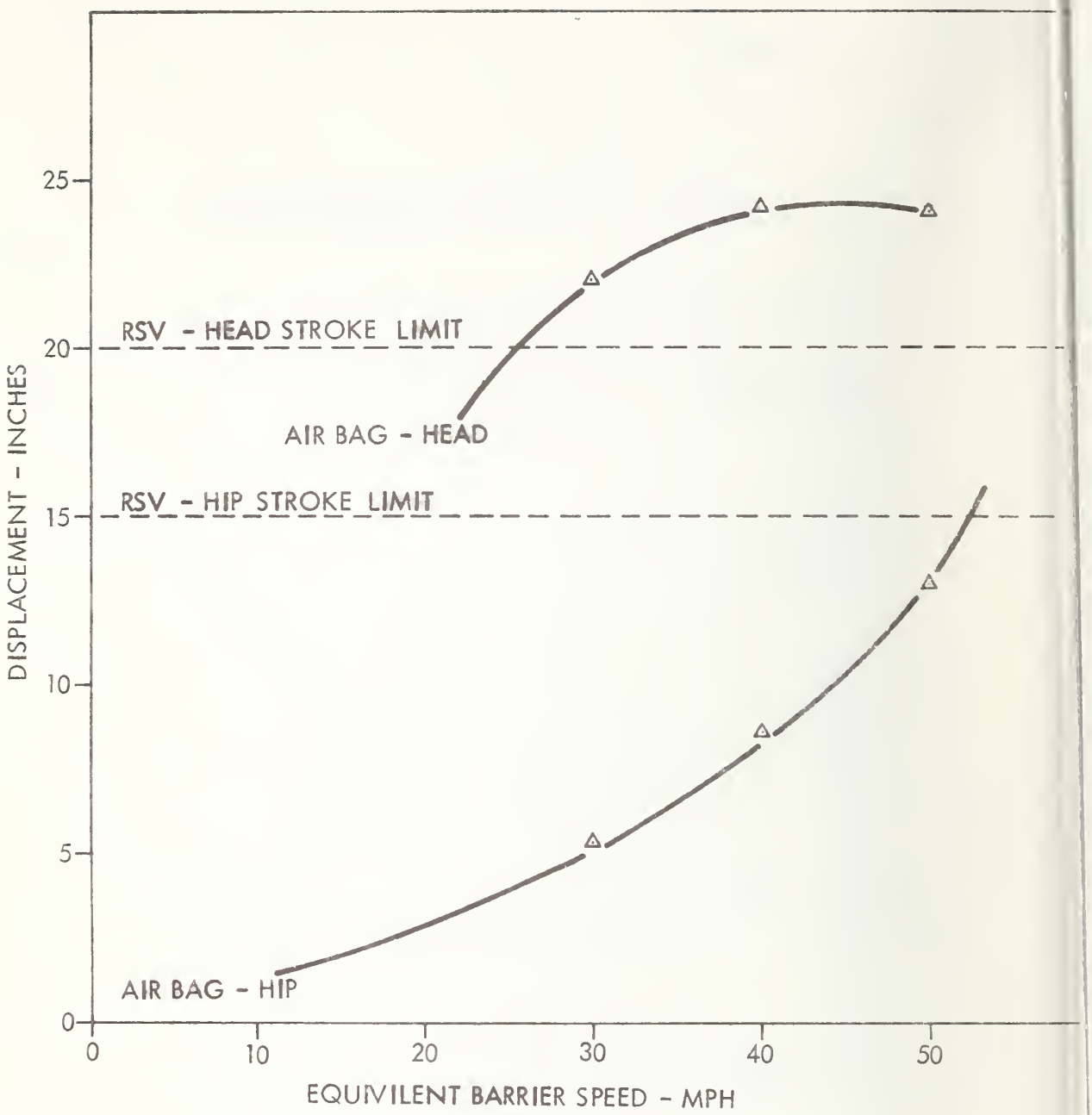


Figure 5-47. Occupant Containment, Pressurized Bag Restraint

Conclusions. It is concluded from this restraint evaluation that both a belt and a pressurized bag restraint system can be used effectively in the RSV for the impact modes and crash signatures proposed, with but moderate modifications to the assumed restraint system characteristics. For a belt system, the results show that a pretensioning device is required to contain the occupant (front seats) during high speed impact (45 mph equivalent barrier). For the bag system, a premium will be required on improving the bag force-penetration characteristics for occupant head containment in high speed impacts.

2.5.3 Flammability

The specifications for flammability have been retained in the same form as presented in the guidelines; no justification for modifications was evident. A comparison of the proposed specifications with previous ESV work is shown in Table 5-24.

2.5.4 Interior Design

The guideline specifications were retained. A discussion of some implied requirements for interior design follows.

It is evident from accident data that most injuries and fatalities resulting from automobile accidents are due to the second collision of the occupant with the vehicle interior. Ideally, it is desirable that the interior configuration be such that the occupant never contacts the interior or when contact is made, the surface yields with a specified limiting force. The former condition is accomplished by a restraint system and a coordinated interior configuration which provides adequate stroking space for the restraint. The latter condition is achieved by the use of interior crash padding appropriately positioned on the surfaces of the vehicle interior, and by properly designing the glazed surfaces to be compliant or to break away during impact. [64,69]

Table 5-24

Comparison of ESV, OESV, RSV Requirements & Specifications

Fire Protection

Specification	ESV	OESV	RSV	Comments
Fuel System	No penetration of fuel cell or connecting lines, no release of fuel under specified crash conditions. Minimum release of fuel from engine.	No penetration of fuel cell or connecting lines, no release of fuel under specified crash conditions. Minimum release of fuel from engine.	No penetration of fuel cell or connecting lines, no release of fuel under prescribed test conditions. Minimum release of fuel from engine.	
Fuel, Electrical & Exhaust Systems	Exclude volatile materials from contacting potential ignition sources.	Exclude volatile materials from contacting potential ignition sources.	Exclude volatile materials from contacting potential ignition sources.	
Interior Materials	Do not support combustion, melt or emit toxic fumes.	Do not support combustion, melt or emit toxic fumes.	Do not support combustion, melt or emit toxic fumes. As a minimum, satisfy FMVSS 302.	
Fire Extinguishment	-	-	Minimum 2.5# hand extinguisher required, rated for Class B & C, small Class A fire.	Easy access or driver or right front passenger, low toxicity required. This dictates position of hand extinguisher between front seats or under center of instrument panel.

In frontal impacts, adequate space can be allocated for unobstructed restraint stroking within the RSV for the front and rear passengers. The driver however must interface with a steering assembly. In current production vehicles, the steering column assembly is designed to collapse when impacted by the driver. Unfortunately, the current columns are designed to collapse in a uni-directional path whereas the impacting driver may be traveling in an oblique direction. To make a steering column compatible for all impact configurations, it must be designed to provide both lateral and axial collapse modes.

In side impacts, the space available for the RSV is inadequate to prevent occupant contact with the vehicle interior. For this crash configuration, the side surfaces (pillars, glazed areas, etc.) must absorb the impact in a manner commensurate with the human tolerance limits of the occupant. Pillars, side structures and other "hard" surfaces will require crash padding. The glazed areas must either be made compliant or designed to break away during impact without producing sharp cutting edges. The proposed occupant protection specification for the RSV interior is compared with previous ESV requirements (representing the current state of the art) in Table 5-25. The comparison shows that for the most part, the requirements for the RSV are reduced somewhat from previous ESV requirements improving chances for technical compliance with lower weight penalties.

2.5.5 Emergency Egress

Accident data does not support the investment of a great deal of cost in emergency egress devices for all the potential accident modes and post-crash conditions specified for the RSV. The specifications are structured to require simple, low cost emergency egress means that would provide cost/benefit ratios appropriate to the frequency of occurrence for the conditions of interest.

Table 5-25

Comparison of ESV, OESV, RSV Requirements & Specifications

Occupant Protection: Without Functional Device

Note: ESV specs as modified during program.
Note: G_R is resultant G level.

Specification	ESV	OESV	RSV	Comments
FRONTAL CRASH				
Velocity	20 mph	DDV[b] + 5 mph	DDV[b] + 5 mph	No restriction indicated on DDV[b]. DDV for ESV 10 mph originally, then 15 mph.
Head Force	60 G_R/3 msec[c]	SI 1000	HIC 1000	Head requirements reduced.
Chest Force	60 G_R/3 msec[c]	60 G/3 msec	60 G/3 msec	
Pelvis Force	60 G_R/3 msec[c]	-	-	
Femur Load	1400	1400	1700	Femur load requirements relaxed.
LATERAL CRASH				
Velocity	20 mph	15[d] mph	22[h] mph	Lateral impact more severe.
Head Force (Lat.)	40 G/3 msec[a]	-	-	
Chest Force (Lat.)	20 G/3 msec[a]	30 G	30 G/3 msec	30 G lateral chest force will be difficult to achieve with imposed dimensional limitations.
Pelvis Force (Lat.)	20 G/3 msec[a]	60 G	-	
REAR CRASH				
Velocity	50 mph[e]	50 mph[f]	40 mph[f]	Rear impact speed relaxed.
Head Force (P-A)	80 G/3 msec	SI 1000	HIC 1000	
Chest Force (P-A)	40 G/3 msec[a]	60 G/3 msec	60 G/3 msec	Chest requirements significantly reduced from original ESV requirements.
Pelvis Force (P-A)	40 G/3 msec[a]	-	-	
Head Rotation	-	-	60°	
OVERTURNING				
Velocity	2 ft drop	30 mph[g]	30 mph[g]	
Head Force (SI)[a]	15 G/3 msec	SI 1000	HIC 1000	
Chest Force (SI)[a]	15 G/3 msec	G_R 60/3 msec	20 G/3 msec	
Pelvis Force (SI)[a]	15 G/3 msec	-	-	

[a] Design Goal.

[b] DDV is design deployment velocity of functional device.

[c] 100 G maximum.

[d] Pole Impact.

[f] Car to Car.

[g] From dolly at lateral velocity of 30 mph.

[h] Equivalent barrier for 35 mph car-car impact with 5000 lb vehicle having specified front end crush characteristics.

Test Considerations

The objective of the RSV Phase I study effort was the development of an RSV performance specification rather than a test specification. It therefore seems more appropriate in this section to elaborate on general certification test requirements rather than on procedural details of each required test. Consequently, an Appendix A similar to that contained in the guideline specifications was not developed; such detailed test conditions and procedures are considered to be appropriate for inclusion in the Phase II program in the form of recommendations for Phase IV.

To realistically evaluate the crashworthy capabilities of the RSV through testing, it is necessary that each test configuration represent the corresponding real life accident configuration as closely as possible. This implies the use of a vehicle simulator with front crush characteristics representative of the striking or impacted vehicles as defined in specification Figure VIII. The simulator must be sufficiently detailed so that the resulting dynamic interaction occurring at the point of impact is closely approximated; this includes such secondary effects as underride/override tendencies, pitching action of impacting vehicle due to panic braking prior to impact, as well as the pitching and yawing action of both vehicles during impact. These secondary effects can be extremely important to the outcome of a collision, especially if these effects result in a collision configuration in which the primary structural load transfer members are not engaged.

Assuming that such a vehicle simulator is available for testing, test configurations must be developed to represent the maximum threat anticipated for the RSV in the 1985 time environment. As indicated in a preceding discussion, the greatest mismatch in vehicle sizes for vehicle-vehicle impacts projected for the 1985 time frame (hence, representing the greatest threat to the RSV) will occur when a 5000 lb vehicle strikes an

RSV. Consequently, the vehicle simulator should be configured to represent a 5000 lb vehicle with front end crush characteristics defined in specification Figure IX.

Specification Figure VIII illustrates the impact design requirements for the RSV. These same conditions can be assumed for testing. For each of these test conditions, four 50th percentile anthropomorphic dummy measurement devices, one located at each outboard seating position, should be used to simulate the kinematic behavior of occupants during impact. As a minimum, the following measurements should be made during each test:

- Vehicle weight (both striking and impacted vehicles)
- Impact velocity
- Passenger compartment acceleration (three axes, front & back)
- Dummy response
  - -Femur load
  - -Chest acceleration (three axes)
  - -Head acceleration (three axes)
  - -Locations of occupant/vehicle contact

3.0 VEHICLE SYSTEMS REQUIREMENTS

The introductory paragraph in this specification was modified to reflect the 1985 time frame and the anticipated continuation of energy conservation measures.

3.1 POWER PLANT, FUEL, COOLING AND EXHAUST SYSTEMS

The emissions requirements that will be in effect in the mid-80's are undefined at present so the reference to the FR data source was qualified to include updating.

The published exhaust emission standards for automobiles driven on the Federal Test Driving Cycle are as shown on the following page.

Emission Standards

1975 Federal Test Procedure

Date	HC	CO	NO_X
		(grams/mile)	
Uncontrolled	(8.7)	(87)	(3.5)
1970	4.1	34	(5.0)
1972	3.0	28	(5.0)
1973	3.0	28	3.1
1974 (California)	3.0	28	2.0
1975	1.5	15	3.1
1975 (California)	0.9	9	2.0
1977	0.41	3.4	2.0
1978	0.41	3.4	0.4

Figures in parentheses show typical values during period when no federal emission standard was in effect.

With the exception of the oxides of nitrogen requirements for 1978, U.S. automobile manufacturers can meet the 1978 standard with non-production, laboratory engines only. Honda's stratified charge engine (1975 CVCC system) is the only known production engine that, except for NO_X, would meet the 1978 levels. Currently, this entire emission standard is undergoing re-evaluation and Congress' decision will establish firmer requirements.

3.2 TIRE AND WHEEL SYSTEMS

FMVSS 109 specifies tire dimensions and laboratory test requirements for bead unseating resistance, strength, endurance, and high speed performance and defines load rating. FMVSS 110 specifies requirements for tire selection to prevent tire overloading. These two standards are adequate for RSV 1985 time frame and are retained.

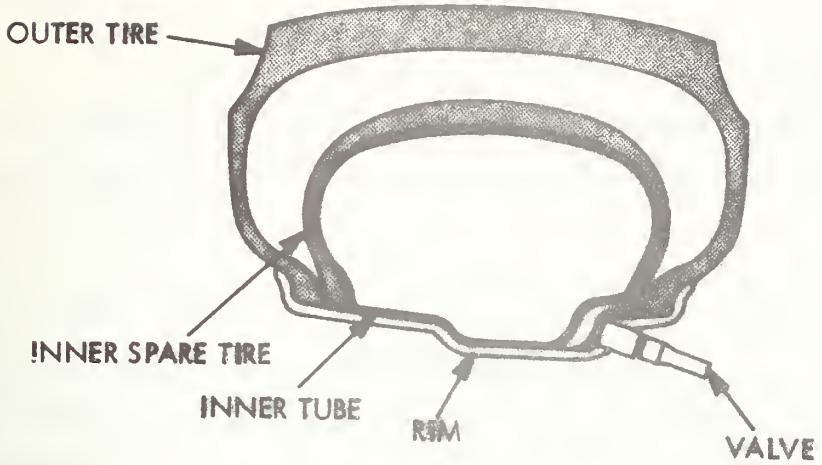
When run-flat tires are used, the probability is that spare tires will be eliminated. Hence, two requirements are added to ensure vehicle safety when driven under run-flat conditions.

The specified minimum clearance of 3-1/2 inches will assure that the vehicle can safely clear the normal pavement irregularities and other roadway debris without mishap. As a comparison, specifications listed in Automotive News for 1974 production models show that the least ground clearance is at a minimum 3.3 inches for Mercury Comet and at a maximum of 7 inches for Cadillac Fleetwood 75.

A travel range of 100 miles at 50 mph ensures in most cases that the vehicle experiencing a tire blowout will be able to reach safely a service station for tire replacement.

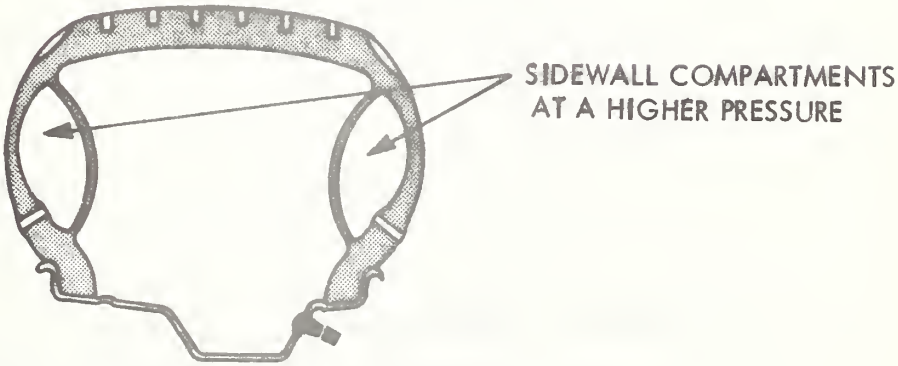
Several run-flat tires are currently under development or on the market. Four types are shown in Figure 5-48. The dual tire concept developed by Goodyear Tire and Rubber Company and Firestone Tire and Rubber Company includes an inner tire and a tube within the outer tire. The inner tire is inflated to a pressure of about 15 psi above the outer tire. Both AMF and Fairchild Industries successfully used these tires on first-generation ESV's. The Dunlop "Total Mobility Tire" derives its run-flat capability from narrow wheels and special tire construction. The Kleber "Get-You-Home" run-flat feature is in sidewall compartments at higher inflation pressure than in the main tire, and the Pirelli "Future Tire" has a near triangular cross section with thick sidewalls in compression to support run-flat loads.

The developers of these tires claim ranges of 50 to 100 miles at speeds of 30 to 60 mph. Hence, the RSV specification of 100 miles at 50 mph is considered to be within the capabilities of 1985 production tire development.

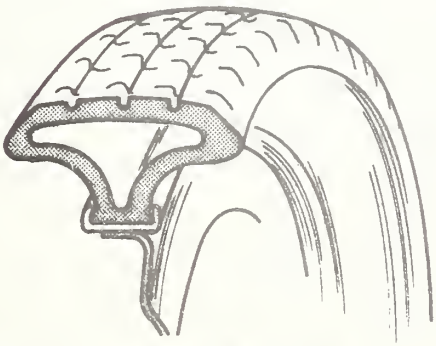


- DUAL TIRE CONCEPT

- DUNLOP " TOTAL MOBILITY " TIRE



- KLEBER " GET - YOU - HOME SAFETY TIRE "



- PIRELLI " FUTURE TIRE "

Figure 5-48. Run Flat Tires

3.3 ELECTRICAL SYSTEMS

Sound engineering and design practices establish the need for these requirements which are essentially the same as those specified in the guidelines.

3.4 INTERIOR COMFORT

The specifications in this section serve to integrate the preceding requirements concerning the interior environment with other comfort considerations in design, and to require several additional convenience features.

3.5 MAINTENANCE

The guideline requirements have been retained with one addition, the incorporation of means to accept external systems to diagnose the functional status of the vehicle. This technology is being developed internationally and steps are being taken to standardize the interfaces between the vehicle and diagnostic systems. While the current state of the art is still exploratory in terms of production applications, some form of diagnostic system is anticipated to be in use within the next decade to cope with the increasing complexity of vehicle systems. [70 thru 75]

4.0 PRODUCIBILITY

Unlike the specifications for the first generation of safety vehicles, those for the RSV must consider the constraints on its design and production imposed by the projected limitations of resources in the mid-80's. The resources of interest to the automotive industry include raw materials, fuels and oils, money for capital investments and for consumer purchasing and maintenance of cars. Further, these limitations are anticipated to apply to all U.S. industries, as well as to foreign industries. Therefore, RSV producibility specifications cannot assume that automotive industry demands can be satisfied by its supporting industries as has been the case heretofore.

Accordingly, Section 4.1 of the specifications addresses all the major resources influencing the materials and fabrication, and assembly processes involved in production designs. Innovative design solutions that assume the industry can find the corresponding solutions to resource limitations will not comply with this specification. However, it is recognized that the resource projections are based on current dynamic and probably, transitory, social, political, and economic experience; therefore, in subsequent phases of the RSV program, identifiable departures from current projections and trends may appear and innovative designs based on these are admissible.

Current and projected material usage and energy considerations in vehicle production is available from various sources; this data can be used for evaluating producibility in terms of material and energy sources. Table 5-26 presents data from one such source which can be [74] used as a baseline for current material usage and for projected usage estimates. A University of Chicago study presents similar data and [75] also treats the benefits to be derived from recycling of junked automobiles.

Iron and steel in various forms are the predominant materials (approximately 74% of the total weight of the car described in Table 5-26) in current production cars and thus have been targets for replacement with alternative materials that result in weight reductions and lowered costs; plastics and aluminum are the prime competitive materials. In the 1974 model year cars, plastic usage averaged 140 pounds and aluminum 80 pounds; projected usage into the mid-80's for both materials [76, 77, is in the 200-300 pound range. These projections probably involve 78] duplications in application and the indicated weight savings potential may not be fully realized. The mid-80 usage estimates consider the dependency of plastics of natural gas and petroleum feedstocks and required plant expansions in the petrochemical and aluminum industries.

Table 5-26

Breakdown of Material & Energy for Manufacture of a 1974 Plymouth Valiant[1]

Materials	Energy BTUs/lb	Lbs/ Car	BTU/Car (Thousands)	Bbls Crude Oil/Car
Plain carbon steel	21,000	1630	34,230	6.113
Stainless steel	34,000	9	306	.055
Alloy steel	22,300	78	1,739	.311
Galvanized steel	21,500	63	1,355	.242
Aluminized steel	21,500	29	624	.111
Cast iron	10,300	436	4,491	.802
Nodular iron	14,050	24	337	.060
Malleable iron	15,500	41	636	.114
Aluminum, rolled drawn	110,000	14	1,540	.275
Aluminum, cast	10,000	56	560	.100
Copper & copper alloys	65,700	26	1,708	.305
Zinc, cast	45,500	28	1,274	.228
Lead	22,000	35	770	.138
Body solder	22,000	6	132	.024
Glass	13,000	79	1,027	.183
Rubber	36,900	183	6,753	1,206
Plastics	25,000	77	1,925	.344
Soft trim	7,000	76	532	.095
Sound deadeners & sealers	7,000	52	364	.065
Paint & protective dip	7,000	23	161	.029
Fluids & lubricants	7,000	146	1,022	.183
TOTALS	538,250	3111	61,486	10.980

[1] 4-door sedan, 225 cu.in. engine, automatic transmission, power steering, power brakes, radio & heater, curb weight 3111 lbs.

Current plastic application, beyond conventional padding and trim, extends to the soft-faced bumper and fender liners while projected applications include rigid foam seat shells, headliners, and outer door panels. The state of the art in aluminum application encompasses bumper bars and engine and trunk compartment panels (the panel application is not considered as production usage but rather as advanced development); projected applications are for all exterior body panels, radiators, and some structural members. The major problems in projected applications of either material are economical rather than technical.

The preceding summary of current and projected materials and applications technology is presented to illustrate the approach and considerations associated with evaluating conformance with specification Section 4.1, Materials and Applications. The development of a full set of criteria for producibility evaluation is considered to be part of the Phase II RSV program.

The requirements specified in Section 4.2, Components and Subsystems, are based on essentially the same considerations as those for materials and applications. The one distinction between the two sections is that components and subsystems are active elements involving a considerable lead time for their development prior to production. This time factor permits a much earlier identification of these elements with some confidence, but presents a related problem in specifying their use in advance of their production time frame. Accordingly, the producibility requirements incorporate Section 4.3, treating the prototype RSV's which may be required well in advance of the mid-80 period.

The producibility specifications incorporate the additional Section 4.3, Prototype RSV, which defines how vehicles, produced in advance of the mid-80 time frame, are to be treated when the technology used in their design is unavailable for implementation in prototype RSV's. This requirement is appropriate to Phases II and III of the RSV program only.

5.0 APPLICABLE DOCUMENTS

The essential document categories contained in the guideline specifications have been retained for the RSV. A listing of specific documents related to technical performance criteria was omitted in favor of the general description of such reports. This approach permits the use of other reports that may become available in subsequent phases of this program and does not exclude the use of current reports that may still be applicable in the future.

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SECTION 5

APPENDIX

TECHNICAL SPECIFICATION

U.S. INTERMEDIATE ESV

DATED: FEBRUARY 16, 1973

AMENDMENT #1

TECHNICAL SPECIFICATION

U.S. INTERMEDIATE ESV

ISSUE DATE: 3/20/75

TECHNICAL SPECIFICATION

U.S. INTERMEDIATE ESV

1.0 GENERAL DESIGN REQUIREMENTS 1

1.1 Objective 1
1.2 Vehicle Description 2

2.0 SAFETY PERFORMANCE REQUIREMENTS 3

2.1 Vehicle Handling and Stability Systems 3

2.1.1 Braking Performance 4
2.1.2 Steering 5
2.1.3 Handling 6
2.1.4 Overturning Immunity 8
2.1.5 Engine and Driveline Systems 8
2.1.6 Ride Performance 9

2.2 Visibility Systems 9

2.2.1 Driver Visibility 9
2.2.2 Lighting 11

2.3 Driver Environment Systems 11

2.3.1 Controls and Displays 11
2.3.2 Warning Devices 12
2.3.3 Environment 13
2.3.4 Emergency Equipment 13

2.4 Crash Energy Management Systems 14

2.4.1 Structural Systems 14

2.4.1.1 Front Structure 15
2.4.1.2 Side Structure 16
2.4.1.3 Roof Structure 16
2.4.1.4 Rear Structure 17

2.4.2 Exterior Protection 17

2.4.3 Fuel System Integrity 17

2.4.4 Pedestrian/Cyclist Protection 17

2.4.4.1 Vehicle Design Requirements . . . 17
2.4.4.2 Vehicle Design Goals 21

2.5 Occupant Compartment Systems 21

2.5.1 Seating Systems 21
2.5.2 Occupant Restraint Systems 22
2.5.3 Flammability 25
2.5.4 Interior Design 26
2.5.5 Emergency Egress 26

3.0 VEHICLE SYSTEMS REQUIREMENTS 26

3.1 Engine, Fuel, Cooling, and Exhaust Systems 26
3.2 Tire and Wheel Systems 27
3.3 Electrical Systems 27
3.4 Interior Comfort 27
3.5 Maintenance 27

4.0 PRODUCIBILITY 28

4.1 Materials and Applications 28
4.2 Components and Subsystems 28

5.0 APPLICABLE DOCUMENTS 29

5.1 Federal Motor Vehicle Safety Standards
5.2 SAE Standards and Recommended Practices
5.3 Program Plan for Motor Vehicle Safety Standards, October 1971

APPENDIX A "Crash Injury Reduction Test Conditions" A-1

ERRATA SHEET

Figure I - Replace with attached figure

Figure II - Replace with attached figure

Page 7 - Subparagraph a, Crosswind Sensitivity, line 6 - "Figure F" should be "Figure V".

Page 11, line 11 and 12 - "The contractor shall justify...study" - delete.

Page 13, paragraph 2.3.3 Environment - The second sentence of second paragraph "The contractor should consider..." should be moved to second sentence of first paragraph.

Page 13, last line - "Latern" should be "lantern"

Page 29 - ADD

5.10 Report No. DOT-HS-820 202, "Measurement of Vehicle Contamination by Exhaust Gases"

Page A-8 - Renumber to Page A-5

Figure I

VEHICLE DECELERATION VERSUS BRAKE PEDAL FORCE

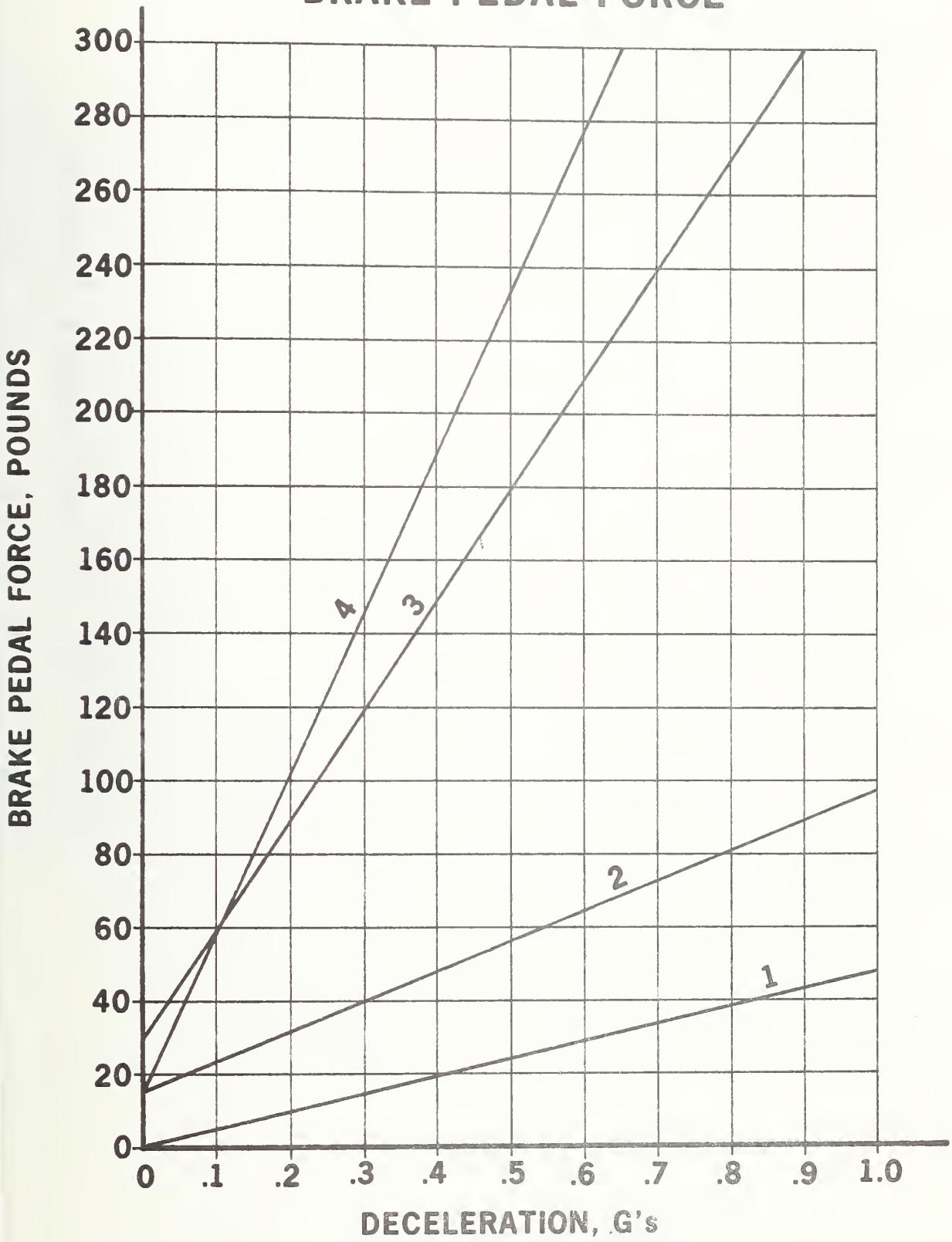
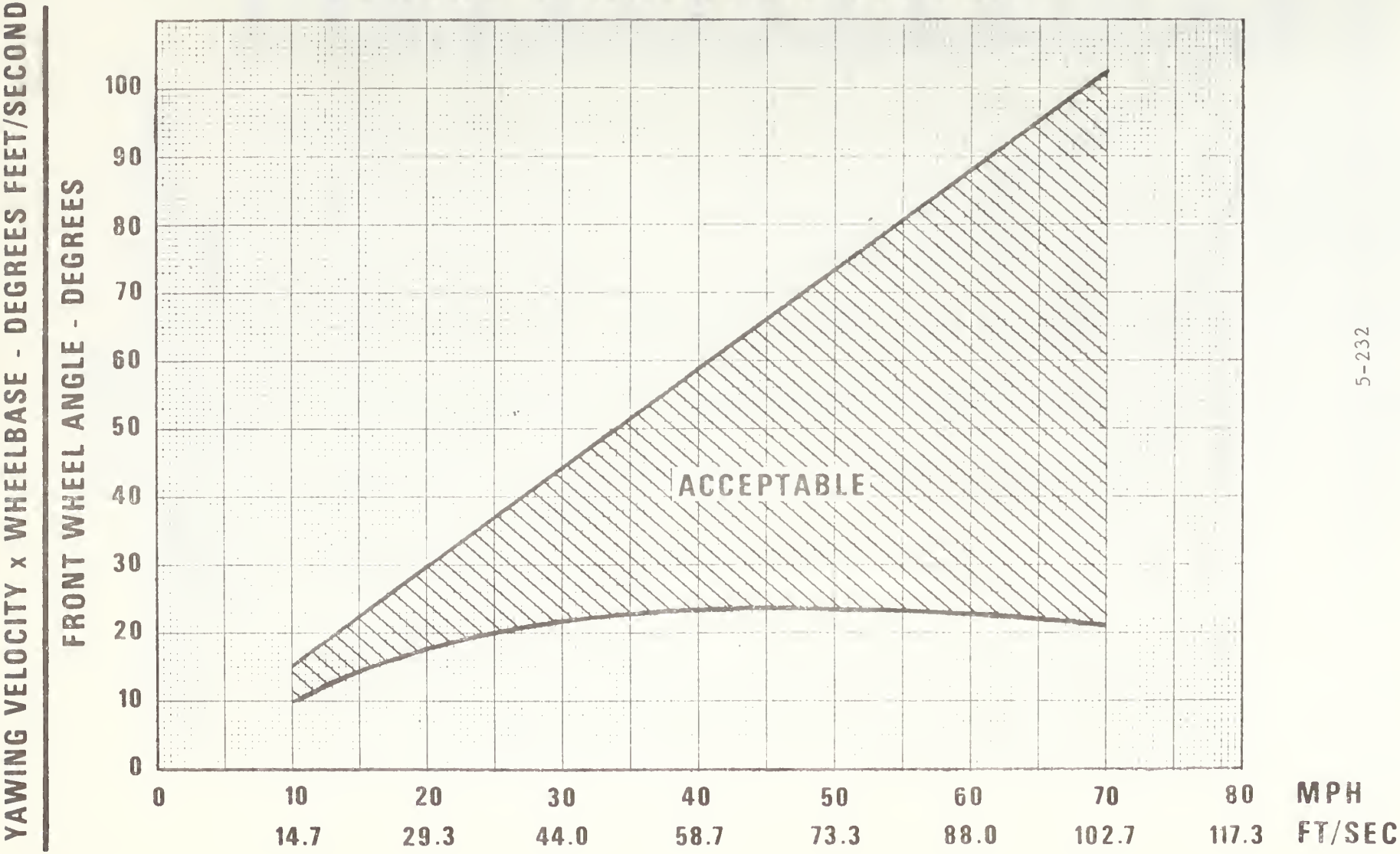


FIGURE 11

STEADY STATE YAW RESPONSE VERSUS TANGENTIAL VELOCITY



5-232

1.0 GENERAL DESIGN REQUIREMENTS

1.1 Objective - 3000 Lb. ESV

The United States Family Sedan ESV Project, initiated in the late 1960's, was directed toward the demonstration of high levels of safety performance in the larger classes of automobiles produced in the U.S. Four different prototype designs have been produced for this class of car and all have successfully shown the feasibility of providing the desired higher levels of safety. Significant research data have been collected, primarily on the structures and restraint systems required for occupant protection, and, in particular, on the problems of collisions between cars of different weights.

In its continuing appraisal of research objectives and goals, for the overall ESV Program, the National Higwhay Traffic Safety Administration (NHTSA) has developed a growing concern for the compatibility of these goals with the evolving national policies on transportation and energy use. The impact of environmental policies on automotive fuel consumption, the economic consequences of higher production and fuel costs, and the pressures for improved mass transportation and traffic control in populous urban areas will all contribute to modifying the U.S. public's attitude toward automotive transportation. In recognition of these considerations, the NHTSA has decided that the more desirable ESV research program for the near-term would be a lighter weight vehicle than was developed in the prototype family sedan project.

Accordingly, we are promulgating the attached set of goals/specifications for a 3000 lb. vehicle for the next phase of the U.S. program. In keeping with the total vehicle concept of the program, all characteristics of the proposed vehicle are addressed. However, vehicle crashworthiness and occupant protection within the weight specification is to be regarded as the core of the program. In most areas other than crashworthiness and occupant protection, general specifications are given in line with current vehicle capabilities. These other characteristics are made available not so much as major engineering challenges as to re-emphasize the total operating vehicle as the eventual output of each phase of the program. As improved goals/specifications in such areas of handling/stability and direct/indirect visibility are developed through concurrent R&D programs, these will be integrated into the ESV requirements prior to actual vehicle fabrication. Thus, the major emphasis during the earlier stages of the 3000 lb. ESV program will be on crashworthiness and occupant protection systems development and test.

It is recognized that the European and Japanese governments and automobile manufacturers have devoted substantial resources and the very best of their technical skills to the development of experimental safety vehicles in the 3000 lb. and lower weight classes in the international ESV program. This second phase of the U.S. program will draw on the significant achievements of these programs, and we shall invite and encourage the continuing exchange of developmental and test data and completed vehicles as we work towards our common goal of safer motor vehicle transportation for everyone.

1.2 Vehicle Description

The vehicle shall meet the following requirements:

General

Body Style	Sedan (2 or 4 door)
Curb Weight	1360 KG/3000 lbs. (max)
Vehicle Capacity	365 KG/800 lbs. (max)

Exterior Dimensions (Reference AMA Specification)

Wheelbase (L101)	2700MM/106 inches (max)
Turning Circle	12.2 meters/40 feet (max)
Overall Length (L103)	4700MM/185 inches (max)
Overall Length/Wheelbase	1.90 (max)
Wheel Tread (W101, W102)	1630MM/65 inches (max)
Overall Width (W103)	1780MM/70 inches (max)
Overall Height (Loaded)	1420MM/56 inches (max)

The angle of approach, angle of departure, and ramp breakover angles shall be as recommended in SAE J689.

Interior Dimensions

The car shall provide seating for at least four occupants including driver. For all design considerations involving the physical size of the occupants, the population to be accommodated shall be at least:

Driver	- Fifth Percentile Female through Ninety-Fifth Percentile Male
Rear Compartment	- Fifth Percentile Female through Fiftieth Percentile Male

The goals for interior dimensions using MVMA passenger car dimension nomenclature are:

	Front (inches)	Rear (inches)
Effective Head Room	38.5 (H61)	38.0 (H63)
Effective Leg Room	42.0 (L34)	37.5 (L51)
Shoulder Room	n/a	60.0 (W4)*

*Shoulder room dimension without occupant restraint devices in position, if used.

Cargo Space

Easily accessible storage and cargo space shall be provided. This space shall include provisions for storing spare wheel and tire (if used) and other road emergency equipment. It is not required, however, that all cargo space be in one contiguous volume or all accessible through one opening.

2.0 SAFETY PERFORMANCE REQUIREMENTS

The performance requirements in this specfication are organized in accord with the Program Plan for Motor Vehicle Safety Standards, October 1971.

In some cases, the requirements and techniques for measuring safety performance that are cited in this document differ from existing or proposed FMVSS's. These deviations were made in order to obtain research data, as well as to evaluate the feasibility of alternate approaches. Where there are differences, this specification shall take precedence.

2.1 Vehicle Handling and Stability Systems

The accident avoidance performance is specified in the sections immediately below. Unless otherwise specified, all tests involving vehicle dynamics will be performed on a surface with a skid number of 70 to 80 with a skilled test driver and the vehicle shall be loaded to 60 percent capacity.

These specifications define the test procedures, values, curve shapes, etc., for determining conformance with contractual requirements relative to vehicle dynamics.

2.1.1 Braking Performance

Service Brake -- The vehicle carrying both 100 percent of rated load and lightly loaded* at 88 ft/sec (60 mph) shall be capable of decelerating to a stop in a distance of 175 feet (22.1 ft/sec^2) without two wheels on any one axle locking up while remaining in a lane 12 feet wide. With the same loading conditions, the vehicle shall also be capable of decelerating to a stop in a distance of 85 feet (20.3 ft/sec^2) without wheel lockup or deviation from a 12 foot lane from a steady state speed of 58.7 ft/sec (40 mph) on a radius of 357 feet (.3 lateral "g"). Steering inputs up to 180° are allowed with rates not to exceed 500°/sec. Fade characteristics and water recovery performance must meet the requirements of FMVSS No. 105a, September 2, 1972.

In accomplishing the performance specified above, the pedal force shall fall between lines 1 and 2 on Figure 1.

In addition, as a minimum the brake system shall employ a two rear wheel anti-lock system and ensure braking performance per Table I where:

E - Brake System Efficiency

F - Tire Factor

R - Brake Rating

M - Wet to Dry Performance Rating

The procedures for calculating the above factors may be found in the HSRI report "A Procedure for Evaluating Vehicle Braking Performance" (DOT-HS-800 628).

Emergency Brake -- In the event of a booster failure or a leakage type failure of a pressure component of the service brake system, other than a structural failure of a master cylinder, the remaining portion of the service brake system shall continue to operate. With the vehicle at 100 percent rated load or lightly loaded and a booster failure

*Defined in FMVSS 105a, September 2, 1972.

BRAKING PERFORMANCE

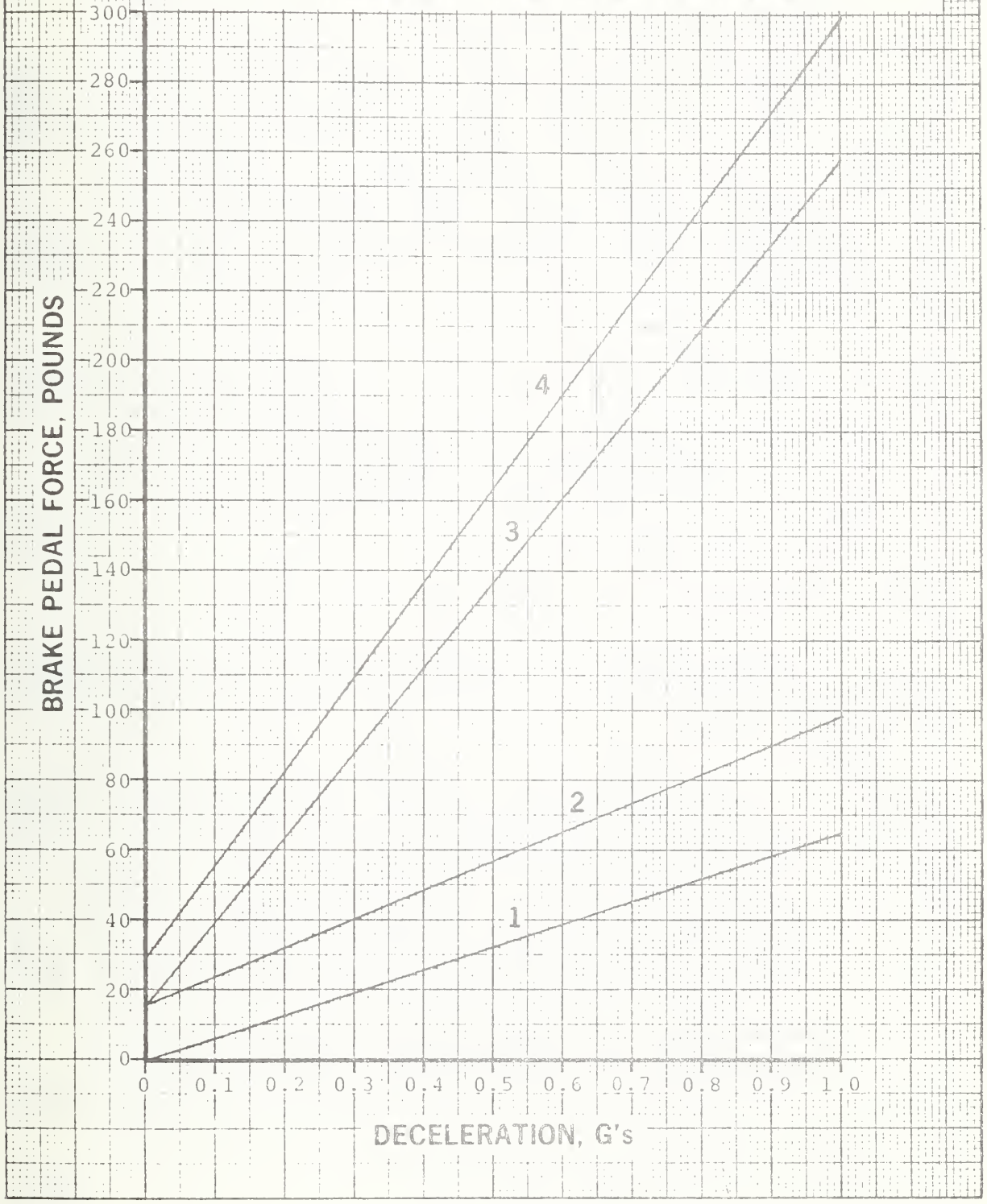
	E	F	R	M
NORMAL	80.0	1.25	100.0	-
FRONT SYSTEM FAILURE	30.0	1.25	37.5	-
BOOSTER FAILURE	40.0*	1.25	50.0	-
WET PAVEMENT	90.0	1.15	103.5	.98
MINIMUM LOAD	90.0	1.25	112.5	-

* - 150 POUNDS PEDAL FORCE

TABLE I

FIGURE I

VEHICLE DECELERATION VERSUS BRAKE PEDAL FORCE



or a front system failure induced into the system, the pedal pressures shall fall between lines one and three and lines one and four, respectively, on Figure I. Vehicle stopping distances from 88 ft/sec (60 mph) shall be as follows:

Booster failure	300 ft. (.40g at 150 lbs. pedal force)
Front system failure	388 ft. (.31g at 150 lbs. pedal force)

Parking Brake -- The vehicle, at curb weight and when fully loaded, using a friction type mechanical brake shall be capable of holding on a 30 percent grade in the forward and reverse directions. Actuation effort shall be less than 90 pounds for a hand system and 125 pounds for a foot system.

Vehicle Jacking -- If run flat devices are used in the vehicle tires, no vehicle jack is required; however, safe jacking points, or areas, must be defined for maintenance purposes. If run flat devices are not provided, a spare tire and wheel and a safe, convenient jack are required. Minimum acceptable criteria for the jacking subsystem have been published as a proposed FMVSS (Ref. 35 FR 17055, November 5, 1970).

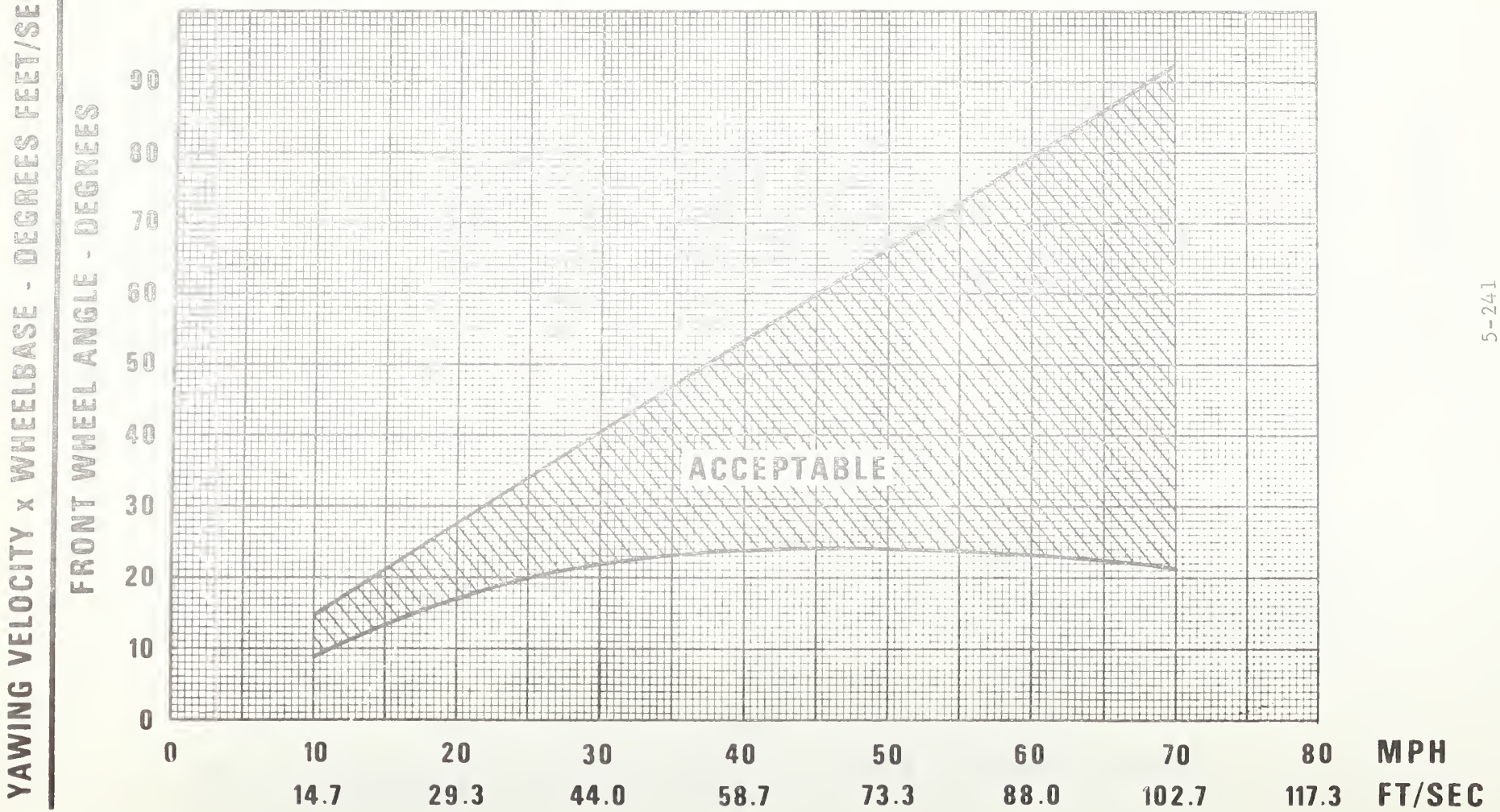
2.1.2 Steering

Yaw Response -- In response to a steering input for which the lateral acceleration is .4g ($\pm$ .02) the vehicle must:

- Maintain a steady state yaw response at forward velocities of 36.7 ft/sec (25 mph), 73.3 ft/sec (50 mph), and 102.7 ft/sec (70 mph) within the envelope defined by Figure II.

- Within this envelope, the specific vehicle response curve must be concave downward at all points. Similar response curves obtained with different lateral accelerations shall exhibit the same characteristic shapes. In relation to the .4g yaw response curve on Figure II coordinates, as lateral acceleration increases from .4g the yaw response curve shall progressively move downward; as lateral acceleration decreases from .4g, the yaw response curve shall progressively move upward.

FIGURE II
STEADY STATE YAW RESPONSE VERSUS TANGENTIAL VELOCITY



5-241

- With a steering input applied at a rate no less than 500°/sec and held constant at a value which produces .4g steady state lateral acceleration with test velocities of 25 mph and 70 mph, the transient yaw response shall be as described below for Figure III. The initial time, T_0, is the time at which one-half the steering wheel input is complete. In this figure, the upper curve is the upper limit for a test speed of 70 mph while the lower curve is a lower limit for a test speed of 25 mph and does not apply to the 70 mph test.

Returnability (Feedback) -- The vehicle shall be driven at 36.7 ft/sec (25 mph) and 73.3 ft/sec (50 mph) around a fixed radius sized to achieve .4g. At a predetermined point of the vehicle path, the driver shall release the wheel completely and the vehicle must:

- Not have a yaw rate greater than 4 degrees per second at any time greater than 2.0 seconds after steering wheel release with a test velocity of 50 mph. From a test speed of 25 mph, the yaw rate 2 seconds after steering wheel release must be less than one degree per second.

- Show steering returnability stability to fall within the envelope defined by Figure IV. In this figure, curve 1 is the upper bound for response with a test velocity of 25 mph; curve 2 is the upper bound for response with a test velocity of 50 mph; and curve 3 is the lower bound for both.

2.1.3 Handling

Lateral Acceleration -- The vehicle shall while travelling on a 100-foot radius skid pad at a constant velocity remain stable with lateral accelerations as shown in Table II. A certification circle shall be completed at plus or minus one mph at the required "g" load with less than 10 degrees total steering wheel movement for the fixed control mode.

Control at Breakaway -- The vehicle shall be operated on a skid pad, in a given circular path, at maximum lateral acceleration (fixed control) until a steady state condition exists. The vehicle speed shall then be gradually increased

FIGURE III
TRANSIENT YAW RESPONSE VERSUS TIME

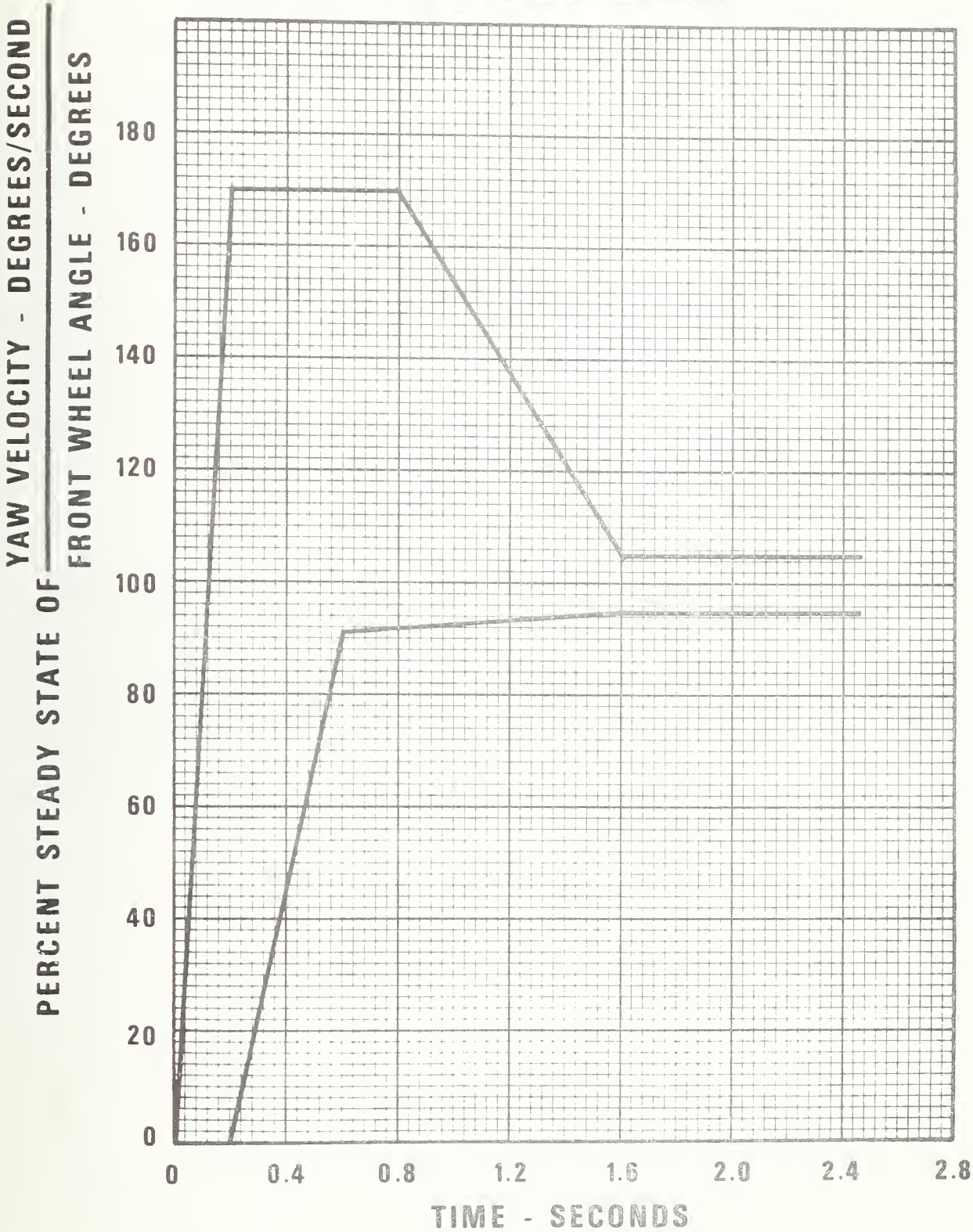
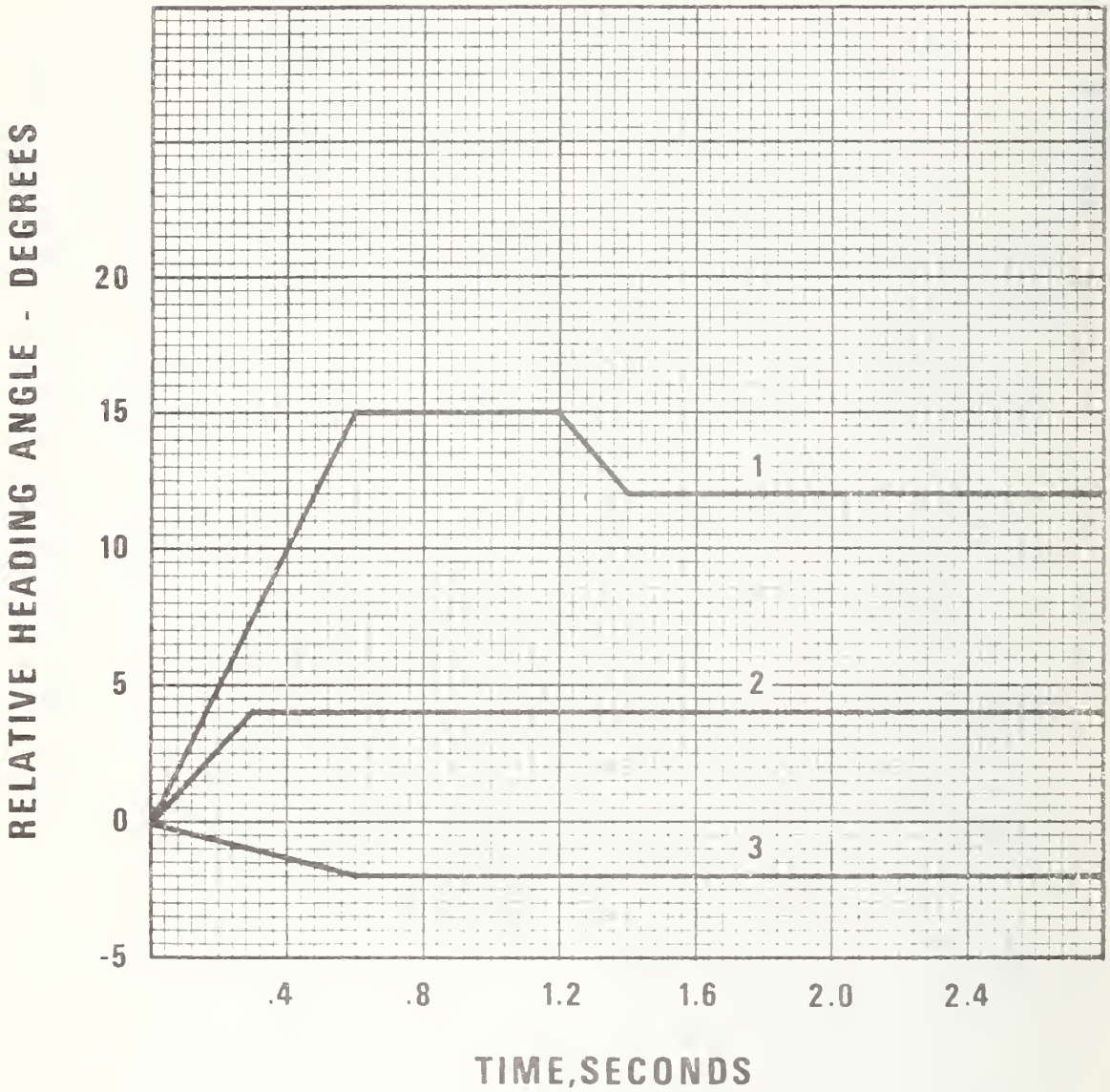


FIGURE IV

FREE CONTROL HEADING VERSUS TIME



SURFACE	TIRE PRESSURE	LATERAL ACCELERATIONS (g)
		FIXED CONTROL
DRY CONCRETE OR ASPHALT	DESIGN VALUE	0.60
	120% DESIGN VALUE	0.60
	80% DESIGN VALUE	0.55
	120% DESIGN FRONT 80% DESIGN REAR	.63
	80% DESIGN FRONT 120% DESIGN REAR	.59
WET CONCRETE OR ASPHALT	DESIGN	* VALUES TO BE RELATED TO ACTUAL PERFORMANCE ACHIEVED ON DRY SURFACE IN PROPORTION TO WET AND DRY TEST SKID NUMBERS.

LATERAL ACCELERATIONS

TABLE II

until any point on the vehicle center line within the wheelbase has moved radially outward a distance of 10 feet from the initial path. At this time, the throttle will be closed initiating the test of control at breakaway. Measuring time from the instant the throttle closes, the vehicle must be capable of regaining and following the initial path (plus or minus two feet) within no more than 4 seconds. This test will be conducted at a steady state circular path of 100 feet and 225 feet radii.

Other conditions to be adhered to in conducting these tests are as follows:

- No braking shall be performed on the vehicle during recovery.
- Steering wheel movements necessary to regain the original path must not be applied at a rate exceeding 500 degrees per second.

Directional Stability -- This parameter will be verified for the following conditions:

- Crosswind sensitivity
- Steering control sensitivity
- Pavement irregularity

The above tests will be run at 44 ft/sec (30 mph), 73.3 ft/sec (50 mph), 102.7 ft/sec (70 mph) and on level pavement with less than 5 mph head-on or tail winds. Specific requirements for each test are outlined below.

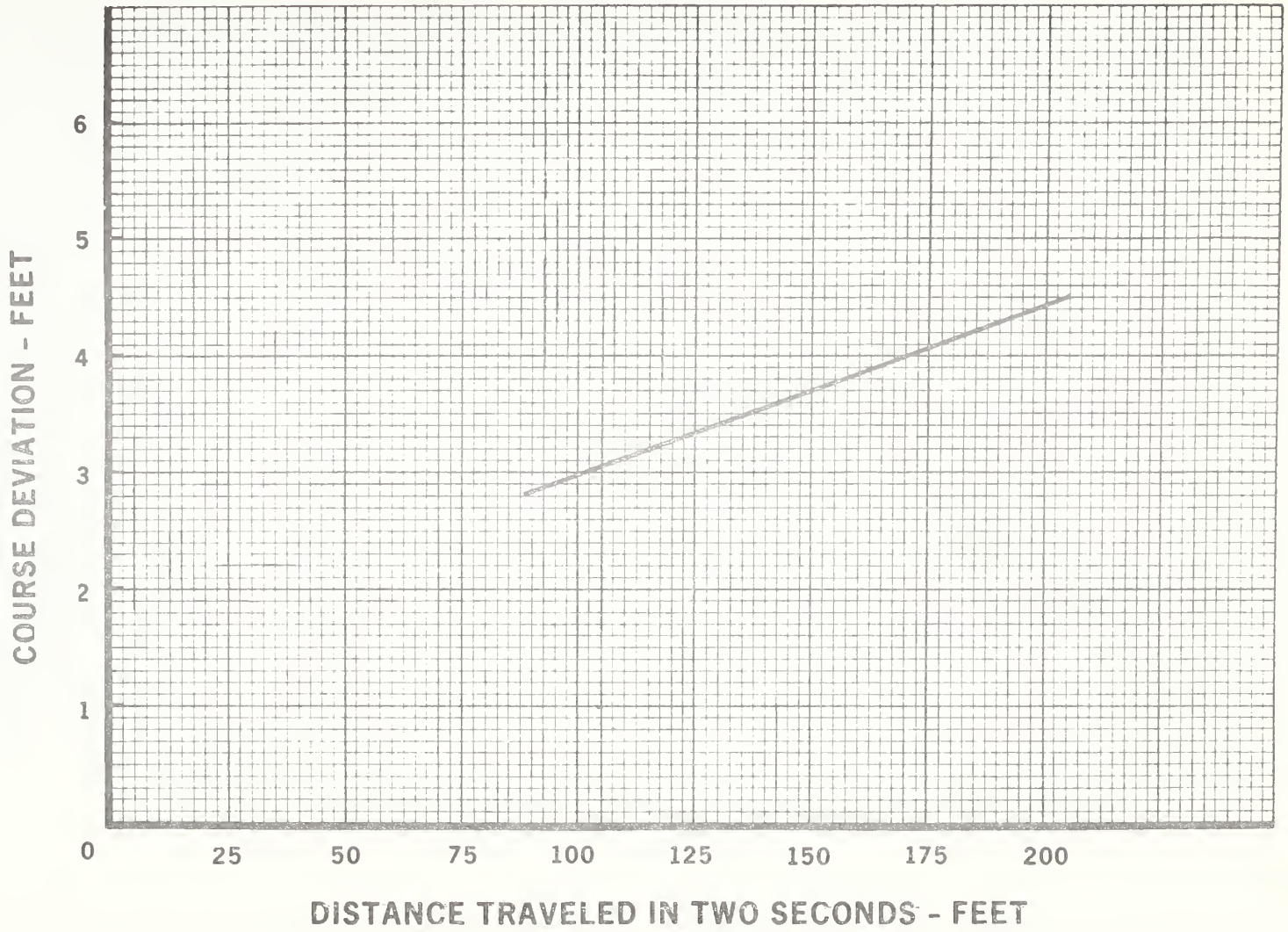
a. Crosswind Sensitivity -- The test vehicle shall be subjected to a step function crosswind application of 73.3 ft/sec (50 mph) plus or minus 7.3 ft/sec (5 mph). Total course deviation for a 20-foot exposure shall be measured 2 seconds after initiating test and shall be less than the value shown on Figure F for the appropriate distance covered by the vehicle in 2 seconds.

b. Steering Control Sensitivity --

   1. The Torque required to cause a yaw rate of 2 degrees per second shall exceed 5 in. pound, applied by a steady force at the rim of the standard wheel.

FIGURE V

ALLOWABLE COURSE DEVIATION VERSUS DISTANCE TRAVELED



2. With the power assist inoperative, the torque required at any velocity above 5 mph shall not exceed the "power on" torque, at the same steering condition, by more than a factor of five.

c. Pavement Irregularity Sensitive -- The course will include a ridge one inch high with a radius of one inch. This ridge shall lie along a line intersecting the directional vector of the vehicle at an angle of 30 degrees. Total allowable course deviation is one foot measured 2 seconds after ridge contact at speeds between 30 mph and 70 mph.

2.1.4 Overturning Immunity

To demonstrate overturning immunity, the vehicle carrying a minimum load shall not overturn under any combinations of braking and/or steering at any velocity on a level paved track. As the minimum, the vehicle must not overturn:

- When negotiating a 1,000 ft. slalom course at the maximum steady state velocity attainable with pylons spaced at 100-foot intervals. A minimum velocity of 50 mph is required.

- When performing the Drastic Steer and Brake* maneuver at initial velocities of 50 and 60 mph.

2.1.5 Engine and Driveline Systems

Sufficient fuel storage capacity shall be provided to permit the vehicle to cruise at 60 mph for a distance of 250 miles.

Passing Time -- With the vehicle 60 percent loaded, the time required to accelerate from 44 ft/sec (30 mph) to 102.7 ft/sec (70 mph) shall be less than 12 seconds.

Lateral Force Influence -- As a minimum, the engine output shall remain constant while the vehicle travels a 100-foot radius circle at the max lateral acceleration for normal tire pressure and manual control. This performance to be verified for 360° of travel while travelling both clockwise and counter-clockwise around the circle.

*Test procedures for this maneuver are described in "Vehicle Handling Performance" Vol. 1, HSRI, University of Michigan, November 1972. (DOT-HS-800 759)

2.1.6 Ride Performance

With a 40 percent load, the natural ride frequencies, measured with the shock absorbers disconnected, shall be between .9 and 1.1 cps for the front suspension and between 1.2 and 1.4 cps for the rear suspension.

2.2 Visibility Systems

2.2.1 Driver Visibility

The driver's field of view requirements are based upon modifications to published notices of proposed rulemaking: the September 1, 1976, requirements for direct field of view (37 FR 7210) and the January 1, 1974, requirements for indirect visibility (36 FR 1156). The modifications are as follows:

a. Point V_0 rather than point M will be used for indirect visibility. If the vehicle is designed to have a very limited range of vision origin points, or a fixed origin point, the point representative of a 50th percentile driver or the single point will replace point V_0 for both direct and indirect visibility measurements.

b. In defining zones for direct visibility, all conical surfaces will be replaced by corresponding planar surfaces; e.g., paragraph S 5.8.1 (c) will read "A plane surface containing point V_2 and forming an angle of 11° with the Y plane."

c. Zone I (ref. paragraph S 5.8.1 (a) and (b)) is modified from 17° left and right of the X plane to 15° left and right of the X plane. Zones II and III are expanded accordingly.

d. Shade bands if used shall meet the requirements of SAE recommended practice J100.

e. Except for shaded areas, covered above, the luminous transmittance in Zones I through V shall be at least 80 percent and that in Zone VI shall be at least 70 percent, as measured per ANS Z26.1, Safety Code for Glazing Materials for Glazing Motor Vehicles Operating on-Land Highways.

f. Sunvisors are required; the specific design criteria will be established by the contractor who will justify the criteria by tradeoff studies.

g. The contractor may elect to eliminate corner reference points (ref. paragraph S 7.2) for other safety considerations; e.g., pedestrian safety. The tradeoff will be justified.

h. Only binocular measurements will be used in determining the obstructed angles in the direct field of view. Binocular or monocular measurements are acceptable for determining target areas visible using indirect systems.

i. The horizontal angular width of obstructions in Zones II and III (ref. paragraph S 9.1 (b)) shall not be more than 6° and that of obstructions in Zones IV and V (ref. paragraph S 9.1 (c)) shall not be greater than 12°. There shall be no more than four pillars (i.e., two "A" pillars and two "B" pillars excluding vent window pillars) in a 270° arc which is 135° to either side of a line passing through point V_0 parallel to the X plane. The steering wheel, windshield wipers and head restraints shall not be considered as obstructions; however, the head restraints shall be designed to provide the minimum obstruction possible consistent with their intended function; e.g., "ring type" or transparent designs. The contractor will justify his design criteria with a tradeoff study.

j. The dimensional criteria for electrical conductors are deleted. The contractor will provide data on the amount of obstruction present in the design.

k. All adjustable indirect visibility devices shall be adjustable from the driver's seat. The right side mirror, if used, may be convex; i.e., a spherical segment with a single radius of curvature having 0.5 or greater magnification at the design eye distance. If system design conditions dictate, the contractor may elect to request NHTSA approval for an indirect visibility subsystem using a stepped inside mirror and/or less than 0.5 magnification for the right hand outside mirror.

There shall be a wiper system for the backlight (rear window) designed to clear 75 percent of the glazing

surface within an unobstructed area of Zone VI. The backlight shall be heated for defrosting purposes.

The car shall meet the requirements of FMVSS 107, with requirements hereby extended to apply to all bright components within Zones I, II and III of the driver's direct field of view. As a minimum, the windshield defrost/defog subsystem shall meet the requirements of FMVSS 103. The contractor shall consider the data developed under contract no. FH-11-6906, "Defog and Defrost Systems," report no. HS-800 192 (Executive Summary, HS-800 193).

The contractor will justify his design criteria with a tradeoff study.

2.2.2 Lighting

As a minimum, the vehicle lighting shall meet the proposed September 1, 1977, requirements (ref. 37 FR 22801); however, the proposed equipment marking of Docket No. 69-19, Notice 2 (ref. 37 FR 17493) will not be required.

If a more advanced headlighting system is incorporated, the contractor shall justify the headlighting photometrics provided versus the control and value of resultant glare. The maximum vehicle forward illumination shall not exceed 170,000 beam candlepower at H-V in any combined or single operational mode.

It is preferred, but not required, that the design will include vertical aim vehicle loading compensation for headlighting systems, dual intensity signal lamp systems, and lamp failure indicators.

2.3 Driver Environment Systems

2.3.1 Controls and Displays

In the design of the displays and controls, in addition to the crashworthiness requirements specified below, human factors must be considered to provide optimum safety features. This includes such items as interpreting instruments, unintentional actuation of controls, etc.

The designer should consider the findings of other NHTSA research contracts; e.g., "Driver Eye Position and Control Reach Anthropometrics," two volumes, report no. DOT-HS-800 618 and DOT-HS-800 619, and "Human Factors Criteria for Vehicle Controls and Displays," five volumes, report no. DOT-HS-800 742 through DOT-HS-800 746.

The vehicle instrumentation shall include, but is not limited to, a speedometer, coolant temperature gage, ammeter, fuel gage and oil pressure gage. The speedometer shall conform to SAE J678d, contain an odometer registering accumulated mileage in increments of 0.1 mi., not register over 85 mph, and be compatible with the speed warning device required below.

The foot pedal designs shall prevent inadvertent simultaneous movement of different foot pedals by the same foot, incorporate non-skid characteristics and be suitable for all foot gear; i.e., including heavy overshoes.

Seat and control adjustment shall be adequate to accommodate individuals ranging in size from a 5th percentile female to a 95th percentile male. Means shall be provided for retaining the driver in such a position that he can operate the steering, service brake and throttle controls under resultant accelerations to 1g.

2.3.2 Warning Devices

The vehicle shall have a horn satisfying the requirements of SAE J377.

The vehicle shall have a speed warning system audible to the driver which sounds at an activating speed which is adjustable by the driver to any speed from 25 to 85 mph. At 85 mph, the speed warning device will be automatically activated.

Warning lights and/or audible signals to alert the driver to mechanical failures; e.g., engine overheat, low oil pressure, door open, or excessive brake lining wear are encouraged. Such devices are not substitutes for instrumentation. They may be combined with instrumentation or installed in a separate on-board diagnostics panel.

There shall be a passive restraint condition monitoring circuit which will provide a visible and audible warning should the system become inoperative.

2.3.3 Environment

There shall be a positive pressure in the passenger compartment under all operating conditions. The carbon monoxide concentration shall not exceed 25 ppm when tested per SAE J989.

The air conditioning system shall satisfy the requirements of SAE J639. The contractor should consider the findings of previous NHTSA sponsored studies, reference "Measurement of Vehicle Contamination by Exhaust Gases," report no. HS-820 202.

The interior noise, vibration and temperature levels shall be comparable to those of deluxe trim, compact size sedans; e.g., Ford Maverick and Chevrolet Nova. The noise and vibration evaluations are intended to be subjective.

2.3.4 Emergency Equipment

Provisions shall be made for readily accessible storage of road emergency equipment. All equipment must be securely mounted to the vehicle and access, if outside the passenger compartment, shall be on the non-traffic side of the vehicle. Equipment shall include:

a. Fire Extinguisher (See 2.5.3)

b. Spare Electrical Fuses (if applicable)

c. Spare V-belts

d. Stopped Vehicle Warning Devices to include:

- three flares
- red emergency reflective triangle (49 FR 393.95 (H))

e. First Aid Kit

f. Tool Kit

g. Electric Latern

2.4 Crash Energy Management Systems

The vehicle shall be designed to provide structural and occupant protection performance as specified in this section. Structural performance requirements are specified to (1) utilize both the structure and interior occupant protection systems to the extent currently feasible in mitigating forces on occupants in the vehicle in all specified crash modes; (2) provide a safe environment for struck vehicles (i.e., low aggressiveness) in collisions with the ESV; (3) provide protection against damage in low speed crashes, and (4) provide a "low hostility" environment in pedestrian crashes. Performance requirements for each of these conditions are established below as a best estimate of desired vehicle capability considering cost effectiveness, practicality, and design achievability. Further analysis shall be performed by the contractor to substantiate these requirements or recommend modifications in accordance with the master schedule.

To simply the specification of performance in this section, all accelerations and decelerations are stated as accelerations; also, all impact velocities, whether forward or rearward, and whether pre-crash or imparted, are stated as velocities.

2.4.1 Structural Systems

The structural systems identified in this specification are basically the primary impact areas. This breakout assumes that related structure such as the floor, for example, will be functionally integrated into the overall structure to complete the vehicle. The primary structural systems are:

a. Front structure

b. Side structure

c. Roof structure

d. Rear structure

The side and roof structures, in addition to being primary impact areas, when combined with the floor form the passenger compartment. For front and rear impacts, loads are transferred to the passenger compartment and in all cases, regardless of the direction of impact, the passenger compartment must protect the occupants from intrusion.

Minimum passenger compartment intrusion consistent with optimized performance and weight are desired. In the absence of technical justification, residual intrusion greater than three inches from the normal inside surface to which the padding or lining is attached will not be permissible with the exception that four inches intrusion will be permissible at the longitudinal center of the door in pole impacts. When greater intrusion is allowed, the contractor shall supply assurance (1) that an increase in intrusion will not significantly increase the probability of entrapment, serious injury or death to the occupants, (2) that the intrusion will be controlled, and (3) that the intrusion can be limited to the approximate values and areas proposed. As an example of the third point, if an intrusion of six inches on the driveline tunnel is proposed in front impacts, assurance should be given that the engine will not cause catastrophic intrusion at an impact velocity slightly higher than the maximum design velocity. Similar considerations apply to rear, side and roof impacts.

The occupant protection requirements given in Section 2.5.2 are applicable for all crash test conditions in Figure VII.

2.4.1.1 Front Structure

A. Barrier Crash Performance -- Figure VI graphically depicts the allowable acceleration of the passenger compartment as a function of impact velocity in the front fixed flat barrier crash modes shown in Figure VII. Single excursions in acceleration of up to five milliseconds duration above the boundary given in Figure VI are permissible. A stroke of the front bumper (and/or the front structure) which is impact velocity sensitive shall also be provided in accordance with Figure VI. The stroke may be initiated at a velocity less than 5 mph provided no vehicle body damage results. After initiation of the bumper movement over the range of impact velocities shown in Figure VI, the remaining stroke shall provide a high

energy absorption efficiency. Two acceleration measurement locations on the frame or rigid structure, left and right, at the longitudinal position of the front seat are designated for determining compliance with Figure VI.

B. Car-to-Car Crash Performance -- The minimum car-to-car performance requirements for head-on crashes are shown in Figure VIII. Table 3 provides energy absorption levels of the ESV under several of the vehicle and closing velocity combinations depicted in Figure VIII. The front structure shall be designed to provide performance in front-to-side crashes in accordance with Section 2.4.1.2 and in front-to-rear crashes in accordance with Section 2.4.1.4.

The front bumper shall provide protection against underride/override when loaded to 40 percent of rated load from a height of 14 inches to 20 inches during either maximum acceleration or panic braking.

2.4.1.2 Side Structure

The side structure/door system shall be designed for side collision at 44 ft/sec (30 mph) when struck under the conditions shown in Figure VII by a vehicle of equal mass with front structure performance specified in Section 4.2.1.1. A second requirement is a collision at 22 ft/sec (15 mph) for a perpendicular impact into a fixed 14" pole as shown in Figure VII.

2.4.1.3 Roof Structure

The roof structure shall be capable of demonstrating satisfactory rollover performance by testing a dolly-mounted vehicle which is rolled from the dolly at a velocity of 30 mph in accordance with the rollover test described in the appended test provisions.

2.4.1.4 Rear Structure

Rear-end crash modes are given in Figure VII. Compatibility with the front structure specified in Section 2.4.1.1 shall be provided.

The bumper shall provide protection against underride/override when loaded to 40 percent of rated load from a height of 14 inches to 20 inches during either maximum acceleration or panic braking.

2.4.2 Exterior Protection

To the maximum extent consistent with the requirements of the specification for crashworthiness for reduction in highway injuries or fatalities, the vehicle shall be designed so as to reduce or eliminate body damage vulnerability in low speed collisions.

As a minimum, both front and rear exterior protection systems shall be capable of sustaining pendulum collision tests of 5 mph as well as barrier collision tests of 5 mph with the vehicle's engine operating and the transmission in neutral position without producing any vehicle body, suspension or driveline damage. The pendulum and barrier collision tests shall be as specified in FMVSS 215.

2.4.3 Fuel System Integrity

No penetration of the fuel tank(s) and connecting lines or release of fuel from these components shall be permitted under all test conditions described within this specification. Release of fuel from the engine shall be limited to the minimum amount practicable for the engine design.

2.4.4 Pedestrian/Cyclist Protection

2.4.4.1 Vehicle Design Requirements

Exterior Geometry -- In the absence of technical justification to the contrary, the exterior geometry of the vehicle shall conform to the following descriptions:

a. The front surface of the vehicle is defined as that portion of the vehicle skin (excluding the

FIGURE VI

PASSENGER COMPARTMENT MAXIMUM ACCELERATION AT FIXED BARRIER IMPACT VELOCITY

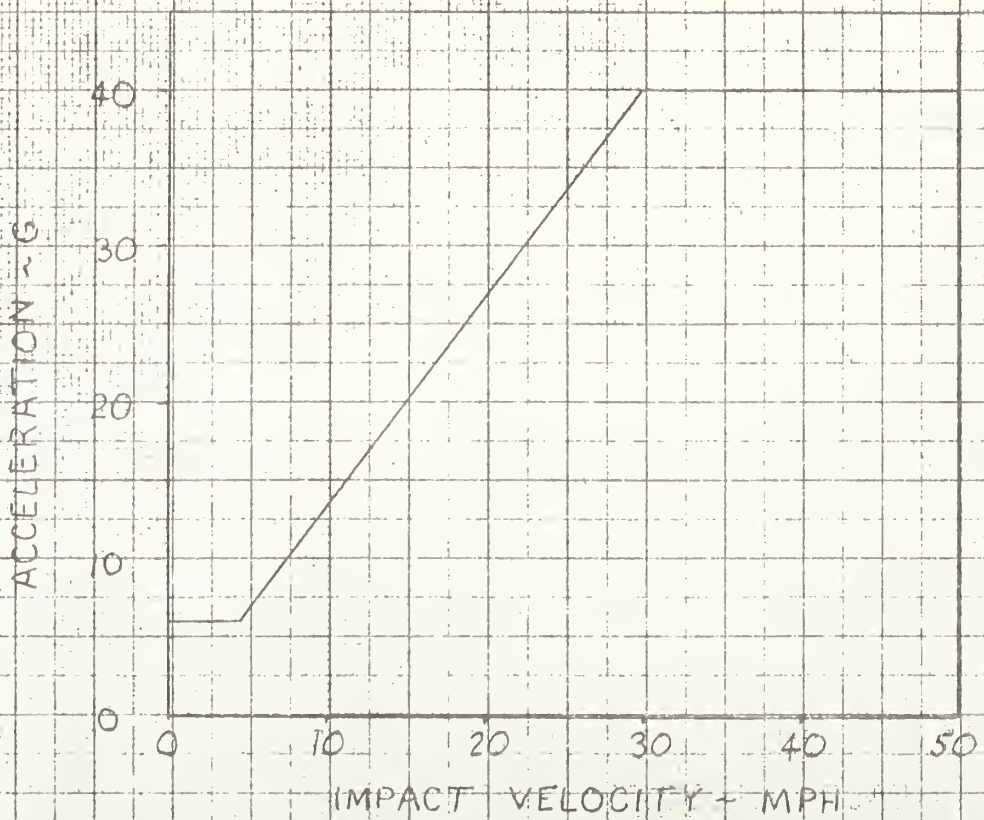
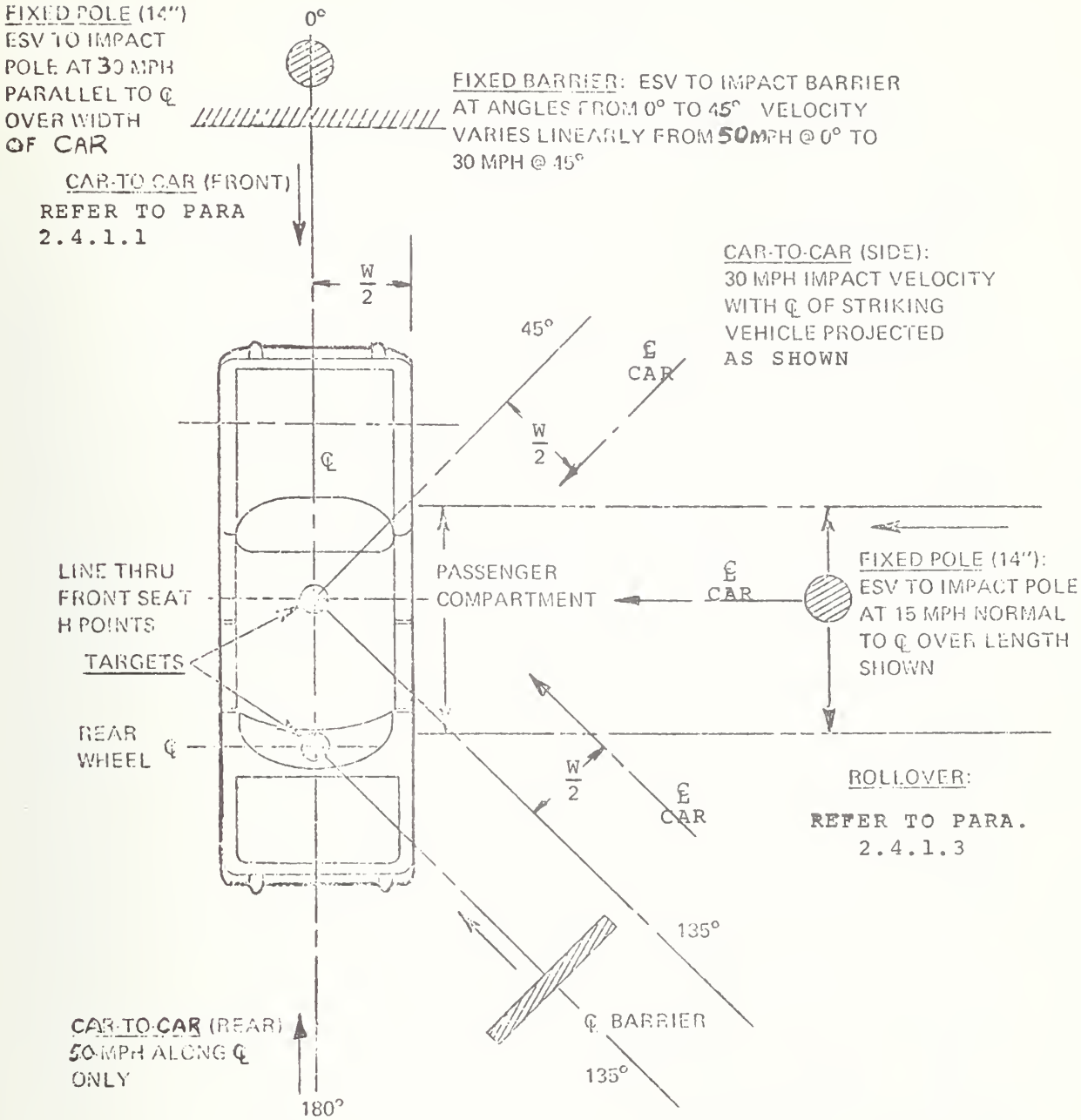


FIGURE VII
DESIGN CRASH MODES



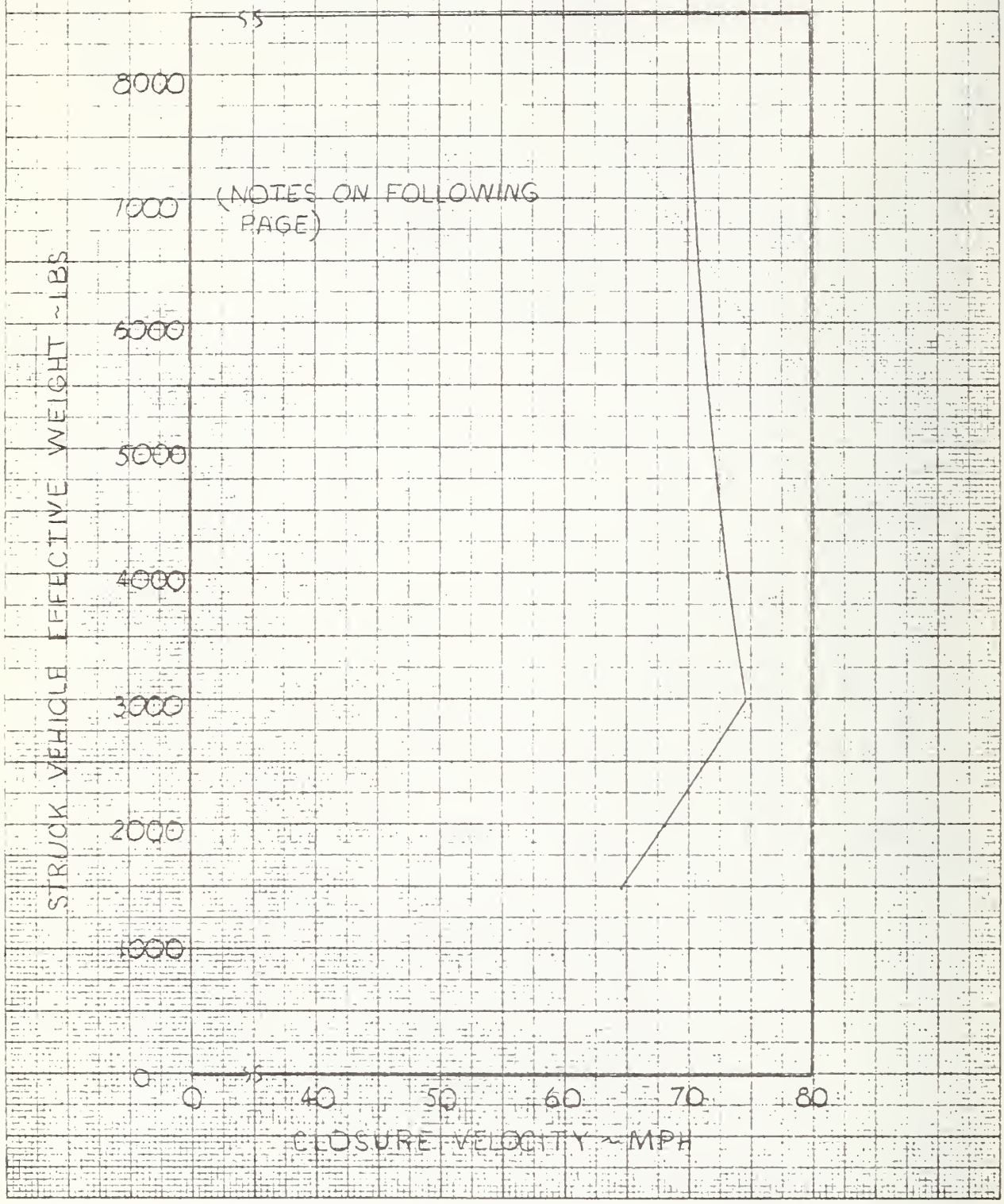
MOVING BARRIER- 4000 LBS.

MOVING BARRIER ℄ PROJECTED THRU TARGET FOR ALL IMPACT ANGLES. VELOCITY VARIES LINEARLY FROM 20 MPH @ 135° TO 27.5 MPH @ 180°.

NOTE: ALL DESIGN MODES TO BE SYMMETRICAL ABOUT ESV ℄

FIGURE VIII

CRITERIA FOR AGGRESSIVENESS



NOTES FOR FIGURE VIII

1. An ESV design satisfying Figure VI

2. Closing velocities which limit maximum vehicle accelerations and crushes to design values

3. Assumptions:

   - ESV effective weight = 3000 lbs.

   - Average acceleration/max acceleration = 0.85

   - Struck vehicles designed for 30g maximum 50 mph fixed barrier collision

   - Collision is aligned head-on and energy absorbing crush is equal to barrier impact crush

   - Struck vehicles designed in accord with principles of Figure VI

TABLE III

MINIMUM ENERGY ABSORPTION REQUIREMENTS OF 3000 POUND ESV

Bogey Vehicle Weight* (lbs)	Frontal Head-on Closing Speed (mph)	Required Energy Absorption in 3000 Pound ESV (ft/lbs)
1500	64.8	33,746
3000	74.8	67,491
4500	72.7	212,942
6000	71.3	212.942
8000	70.2	212,942

*Test bogey vehicles designed with the following characteristics in fixed rigid barrier impacts:

Test Bogey Weight (lbs)	Barrier Impact Velocity (mph)	Constant Dynamic Crush Load (lbs)	Dynamic Crush Stroke (inches)
1500	50	45,000	28.4
3000	50	90,000	28.4
4500	26.4	90,000	13.9
6000	25.2	90,000	16.9
8000	23.4	90,000	19.5

bumper) forward of the leading edge of the windshield. The rear surface of the vehicle is defined as that portion of the vehicle skin (excluding the bumper) rearward of the trailing edge of the backlight. The front and rear surface of the vehicle shall have the following geometry.

- The intersection of the front or rear surface and any intersecting horizontal plane shall describe a convex curve with the apex lying on the vehicle centerline.

- The intersection of the front or rear surface and any intersecting vertical plane which is parallel to the longitudinal axis of the vehicle shall describe a convex curve. The extreme forward or rearward point (as appropriate) of the curve shall be located at the lowest extremity of the vehicle front or rear surface (as appropriate).

- The vehicle skin adjacent to each wheel well shall be contoured as required to preclude protrusion of any portion of the wheel/tire beyond an imaginary surface bounded by the rim of the wheel well opening. In the case of the front wheels, this requirement applies only when the wheels are in a zero yaw position.

b. The side surfaces are defined as those portions of the vehicle skin and glazing that are located between the leading edge of the windshield and the trailing edge of the backlight and lie in a general vertical plane parallel to the longitudinal axis of the vehicle. The side surfaces shall have the following geometry.

- The intersection of a side surface and any intersecting vertical plane which is perpendicular to the longitudinal axis of the vehicle shall describe a convex curve with the extreme outboard point located at the lowest extremity of the vehicle side surface. This requirement does not necessarily include the side glazing.

° The geometry of all side glazing and the design of any adjustable side glazing shall preclude protrusion of any portion of the side glazing beyond an imaginary surface bounded by the adjacent vehicle skin.

c. All bumper faces shall be vertical and shall have a vertical dimension of at least 8 inches.

d. The wheel covers shall cover the entire wheel and shall have a convex shape.

Exterior Finish -- The finish applied to the vehicle skin, bumpers and wheel covers shall contain no abrasive or frictional materials except as may be required to enhance the control of pedestrian/cyclist dynamics during and/or after impact.

Exterior Protrusions -- Exterior vehicle protrusions, other than those provided expressly for pedestrian safety, shall be eliminated or recessed to the maximum extent feasible. Protrusions other than those provided expressly for pedestrian safety which cannot be eliminated or recessed shall be designed to crush or break away when contacted from any direction if (a) a pressure of 80 psi is exceeded, or (b) a pressure of 50 psi is maintained for a period of more than 5 milliseconds.

Energy Absorption -- In the absence of technical justification to the contrary, the designs of those portions of the vehicle (excluding bumpers) that are forward of the leading edge of the front tires and rearward of the trailing edge of the rear tires shall incorporate energy absorption features with performance characteristics indicated by the following test environment.

When a body block of the type described in SAE recommended practice J944a is impacted against the vehicle in accordance with the conditions listed below, the longitudinal acceleration of the body block, measured at a point on the body block backing plate which is 18.0 $\pm$ .25 inches from the top of the head on the vertical axis and at the center of the lateral axis, shall not exceed 60g, except for time intervals of no more than 3 milliseconds duration.

- Impact velocity shall be 25 mph.

- At the instant of impact, the body block shall be travelling in a horizontal plane toward the passenger compartment on a path that is at any angle between 0° - 30°, inclusive, to the longitudinal axis of the vehicle.

- At the instant of impact, the body block backing plate shall be tangent (to the maximum extent that can feasibly be determined) to the vehicle surface at the impact point. If the vehicle impact point lies between the inner edges of the front tires (in zero yaw position), body block deflection shall be allowed only in a vertical plane parallel to the longitudinal axis of the vehicle. If the vehicle impact point lies outboard of the inner edge of either front tire (in zero yaw position), body block deflection shall be allowed in any upward direction.

- The body block impact point shall lie anywhere on a horizontal line 18.0 ± .25 inches from the top of the head.

- The body block shall not contact the bumper during impact.

All exposed bumper surfaces shall be covered with energy absorbing material. The amount and characteristics of the material used shall be commensurate with minimizing pedestrian injuries.

Visibility -- No requirements exist beyond those specified in paragraph 2.2.1 of this specification.

Audio/Visual Signaling -- A driver operated audible signaling device shall be provided as specified in paragraph 2.3.2 of this specification.

A backup alarm device shall be mounted on the rear of the vehicle and shall be activated automatically when the vehicle transmission is placed in reverse. This alarm shall produce a continuous series of discrete, audible (5-10-KHz) signals at intervals of 1-2 signals per second. The duration of the signals and the duration of the time intervals

between signals shall be approximately equal. The sound level of the signals shall be 82 ± 3 dbA at a horizontal distance of 25 ft. behind the rearmost point of the vehicle at a height of four feet above ground level when measured in accordance with paragraph four of the SAE recommended practice J994 (modified for a 25 ft. microphone distance).

No visual signaling devices are required other than those specified in paragraph 2.2.2 of this specification.

2.4.4.2 Vehicle Design Goals

Provisions should be made for positive control of the trajectory of pedestrians or cyclists who are impacted by the front of the vehicle at velocities above 10 mph. In this situation, the pedestrian/cyclist should be (1) propelled onto the vehicle hood if initial contact is between the inner edges of the front tires (in zero yaw position) and (2) propelled onto the vehicle hood (preferable) or propelled out of the vehicle path (as a minimum) if initial contact is outboard of the inner edge of either front tire (in zero yaw position).

Provisions should be made for positive retention (on the vehicle hood) of a pedestrian or cyclist who has landed on the vehicle hood.

In conjunction with the above paragraphs, the vehicle hood design should incorporate injury attenuating energy absorption.

2.5 Occupant Compartment Systems

2.5.1 Seating Systems

The front and rear seating systems shall be designed to provide reasonable occupant protection under all test conditions described in this specification. The seating systems shall be functionally integrated with occupant restraint system performance.

During rear vehicle impact the seats shall provide adequate head, back and whole body restraint to retain the occupant, prevent hyperextension of the neck, and assure that tolerable occupant acclerations and local loadings are not exceeded. Rearward translation and deflection of the front seats shall be limited to the extent necessary to prevent imparting injury-producing loads on rear seat occupants and to assure retention of front seat occupants.

In frontal vehicle impacts, the seat systems shall not impose injury-producing forward loads on the occupants during or after decleration of his forward motion. The seat systems shall provide adequate impact attenuation to prevent exceeding human tolerance levels on occupant loading resulting from any rebound phase of the occupant restraint system.

In angular and lateral vehicle impacts, the seat system shall be integrated with door padding, consoles and other interior components to limit loading of the occupants to tolerable levels. The seat systems shall also limit vertical loading on the occupants to tolerable levels during all operating and crash conditions under which they are contacted by the occupant.

The seat and head restraints shall satisfy all requirements of FMVSS 201 and 202 as a minimum. For unique head restraint designs which make compliance with the specified test conditions of the FMVSS 202 technically inappropriate, the system must, under the conditions of maximum forward vehicle acceleration resulting from prescribed vehicle design conditions of Section 2.4, restrict head rotation relative to upper torso to angles not exceeding 60° and head impact conditions to values not exceeding head injury criteria value of 1000 as defined in FMVSS 208.

2.5.2 Occupant Restraint Systems

Load distributions on various portions of the body are known to be critical parameters influencing serious occupant injury and survival. Human tolerance to localized loading (in terms of load per unit area) is not currently adequately defined. It is therefore a goal in this program to utilize practical means to minimize local load applications to the body.

To the extent practical, all controls and interior protrusions shall be recessed or shielded making them noncontractable by an occupant whether restrained or not. Where this is not practical, all contactable interior protrusions shall be frangible, crushable or have breakway properties. All other interior surfaces shall minimize local forces on the occupants. A design goal shall be that no more than 50 psi contact pressure shall be developed for more than five milliseconds between any interior surface or protrusion and a colliding occupant for all directions and magnitudes of test specified in this work statement. Short-time peaks in pressure greater than 50 psi, but not to exceed 80 psi, will be allowed for periods not to exceed five milliseconds.

Vehicle interior surfaces which are contactable by the face of an occupant during crash shall be designed to provide no greater than a 200 pound resistance to penetration of a 6 1/2 inch diameter rigid head form weighing 11.5 pounds during dynamic impact of the crash condition until a one inch penetration has been exceeded. During the initial one inch penetration of the head form at least 50 inch pounds of energy shall be absorbed. Transparent glazing shall not be subject to these requirements at this time.

For all directions and magnitudes of crash tests specified herein, the additional injury criteria (a) through (e) shall not be exceeded.

(a) All protions of the test device shall be retained within the vehicle passenger compartment throughout the test.

(b) The resultant acceleration at the center of gravity of the head shall not exceed a head injury criteria level of 1,000 calculated by the method described in FMVSS 208.

(c) The resultant acceleration at the center of gravity of the upper thorax shall not exceed 60g, except for intervals whose duration is not more tnan three milliseconds. Additional restrictions on the acceleration magnitude along the orthogonal axes shall be: A-P acceleration shall not exceed 60g for periods exceeding three milliseconds duration; S-I acceleration shall not exceed 20g for periods exceeding three milliseconds; lateral acceleration shall not exceed 30g for periods exceeding three milliseconds.

(d) The force transmitted axially through each upper leg shall not exceed 1,700 pounds.

(e) Rearward angular displacement of the head reference line shall be limited to 60° from the torso reference line under the specified vehicle rear impact conditions in Figure VII.

An onset rate of 1500g per second or less shall be a design goal for the occupant chest when the following conditions exist:

1. A change in g level up to 20g occurs, and

2. When upper g level is sustained for a period up to 10 milliseconds.

Occupant protection systems for the driver and right front passenger shall require no voluntary action by the occupants. This may include devices which are automatically operated or deployed to increase occupant protection in crashes above some predetermined speed. Such occupant protection mechanisms are acceptable provided that the occupants are not required to perform any voluntary functions to initiate operation, that the operation is accomplished without exposing the occupants to alternate hazards, and that the mechanism has high performance reliability under normal automobile service conditions.

An occupant protection system which includes a functional mechanism for crashes above a specific speed shall be capable of satisfying the requirements of (a) through (d) above at crash speeds 5 mph higher than the predetermined speed without benefit of the mechanism or device as well as with the function at 5 mph lower than the predetermined speed.

For the rear passengers, first priority shall be given to the outboard seating positions for all crash modes. Selection of the occupant protection system shall be based on a study of the relative cost benefit merits of alternative systems.

2.5.3 Flammability

The fuel, electrical, and exhaust systems shall be designed to assure containment of fuel in a variety of crash modes, as well as the exclusion of volatile materials coming into contact with potential ignition sources. Possible interaction of the systems from the standpoint of design features and structural deformation effects must be considered.

Interior materials that will not support combustion, will not melt, and will not emit toxic fumes when exposed to flame and/or extremely high temperatures will be used to the extent practical. As a minimum, all materials used in the occupant compartment must satisfy the requirements of FMVSS 302.

A small fire extinguisher (not to exceed 2.5 pounds in weight) shall be provided in the occupant compartment of the vehicle and include, at a minimum, the following features:

a. The extinguishing agent should be rated for Class B** and Class C*** fires and be capable of extinguishing small Class A* fires.

b. The extinguishing agent when used under fire conditions should not have severe or prolonged harmful effects on humans.

c. The extinguisher should be small enough to be located within easy access of the vehicle driver and the right front passenger.

d. The extinguisher should be inexpensive, easily recharged, and easily inspected.

*Class A Fires - those involving a solid fuel, such as wood, paper, or textiles.

**Class B Fires - those fueled by flammable liquids, such as gasoline, oil, grease.

***Class C Fires - electrical fires.

2.5.4 Interior Design

Interior occupant compartment design shall satisfy FMVSS 201 as a minimum.

2.5.5 Emergency Egress

The design of the ESV will include provisions for occupant escape or rescue from the passenger compartment in any attitude it may have as a result of collision, rollover, or submersion. Geometry and space available for the large variations in age and size of occupants must be considered. Operational features of latch and release mechanisms under adverse conditions of injury, panic, darkness and unusual vehicle orientations must also be considered.

3.0 VEHICLE SYSTEMS REQUIREMENTS

In accord with the ESV Program objectives, the major content of this specification is directed toward vehicle safety performance. It is required, however, that in all non-safety systems operations the performance be at least equivalent to state-of-the-art production vehicles. The vehicle systems shall be designed to withstand normal service conditions and/or loads encountered throughout the life of a normal production vehicle without failure. No unusual maintenance or servicing actions shall be required and routine replacement items (e.g., tires, batteries) shall be readily available to the consumer.

The minimum systems requirements in addition to any safety performance requirements are defined below.

3.1 Engine, Fuel, Cooling, and Exhaust Systems

The engine fuel and engine exhaust systems shall meet all requirements for control of air pollution from new motor vehicles and new motor vehicle engines as specified in Federal Register, Vol. 37, No. 221. The standards used for exhaust emissions shall be for 1976 and later model year vehicles. Tests will be conducted by the contractor to obtain emission data on one vehicle; no durability tests will be conducted.

The engine cooling system shall be designed to perform in accord with normal industry standards. Engine coolants shall comply with SAE J814 and system materials shall provide for satisfactory service life.

The exhaust system shall be designed in accord with standard automotive practice and shall be fabricated from materials which will provide for acceptable service life.

3.2 Tire and Wheel Systems

To assure availability of replacement tires and wheels, the tires shall be limited to load range "B" tires and wheels shall be steel. No unusual rubber compounds shall be specified for the tires.

3.3 Electrical Systems

The electrical system shall be designed to accommodate all normal operating loads (engine ignition, lighting, brakes, etc.) and normally utilized accessories such as radio; an air conditioner is desirable for this car but not required. Wiring harnesses, fuses, alternator/generator and storage battery shall all be sized for sufficient margin to provide economical and low maintenance operation over the life of the vehicle.

3.4 Interior Comfort

Provisions shall be made for driver/passenger comfort in accord with conventional automotive practice. This shall include fresh air ventilation, air conditioning, courtesy lighting, radio and clock. Engine compartment heat shall be controlled with thermal insulation and noise insulation shall be applied to reduce engine/road noise. Interior storage shall be provided, such as a glove compartment, map pocket, etc.

3.5 Maintenance

All vehicle systems shall be designed to withstand service conditions or loads throughout the equivalent life of a normal production vehicle. In all systems, ease and economy of maintenace as well as safety of maintenance operations shall be considered.

4.0 PRODUCIBILITY REQUIREMENTS

Although this is to be an experimental vehicle that will be produced in limited numbers, the requirements of volume production shall be considered in the design of all systems. This will include such parameters as cost, weight, tooling and fabrication, materials selection, inspection and quality control, and manpower skills. The innovative application of technology that could be used by the industry on a cost effective basis in the near future is not discouraged; however, extensive requirement for materials, processes, or components not amenable to cost effective industry-wide application will not be acceptable. The assumptions for production estimates are that annual model year production is 300,000 units and that the basic model would be produced for at least five years.

4.1 Materials and Applications

The projected high volume production of this ESV design shall be shown to follow common automotive industry practice in the application of materials. The amounts of any special or non-standard materials may be increased over current usage if based on reasonable growth projections and the assumed production runs.

The utilization of any materials shall be at the discretion of the contractor unless otherwise limited by this specification. All applications must comply with reasonable automotive practice, however, and must be capable of high volume production.

4.2 Components and Subsystems

Functional subsystems (brakes, steering, ignition, etc.) shall be designed to utilize parts, components, and subsystems that are economically feasible for high volume production. To the maximum extent possible, all systems shall reflect advanced automotive designs as projected for the 1980's. It is recognized, however, that developmental costs and/or market competition may constrain the use of developmental or prototype products. The contractor may select priority safety systems or other functional systems for developmental demonstration of advanced concepts where significant safety, economic, or weight improvements can be shown.

5.0 APPLICABLE DOCUMENTS

5.1 Federal Motor Vehicle Safety Standards

5.2 SAE Standards and Recommended Practices

5.3 Program Plan for Motor Vehicle Safety Standards, October 1971

5.4 Federal Register (as referenced)

5.5 Report no. DOT-HS-800 628, "A Procedure for Evaluating Vehicle Braking Performance"

5.6 Report no. DOT-HS-800 759, "Vehicle Handling Performance," Vol. 1

5.7 Report no. DOT-HS-800 192, "Defog and Defrost Systems" (Executive Summary HS-800 193)

5.8 Report no. DOT-HS-800 618 and DOT-HS-800 619, "Driver Eye Position and Control Reach Anthropometrics" (two volumes)

5.9 Report no. DOT-HS-800 742 through DOT-HS-800 746, "Human Factors Criteria for Vehicle Controls and Displays" (five volumes)

APPENDIX A

Crash Injury Reduction Test Conditions

1. General Conditions - The following conditions apply to crash tests for the frontal, lateral, rear and rollover design crash modes shown in Figure VII.

   1.1 The maximum test weight of the vehicle shall not exceed the vehicle curb weight plus its rated cargo capacity weight of 800 pounds.

   1.2 Adjustable seats are in the position commensurate with the size of the anthropomorphic test device being used.

   1.3 Adjustable seat backs are in the nominal design riding position.

   1.4 Adjustable steering controls are adjusted so that the steering wheel position is commensurate with the size of the anthropomorphic test device being used.

   1.5 Movable vehicle windows and vents are in the fully closed position.

   1.6 Doors are fully closed and latched but not locked.

   1.7 Anthropomorphic test devices conform to the general requirements of SAE recommended practice J963, June 1968, and have a pelvic structure that conforms to Figure 1-A. The weights, dimensions and centers of gravity specified in SAE J963 for the test device segments are determined with all instrumentation in place.

   1.8 Each test device is clothed in form-fitting cotton stretch garments.

   1.9 Limb joints are set at 1g, barely restraining the weight of the limb when extended horizontally. Leg joints are adjusted with the torso in the supine position. Articulated head, neck and torso joints do not move at a horizontal acceleration load of 1g, in the test position, but move at a horizontal acceleration load of 2g.

1.10 Each test device is firmly placed in a designated seating position in the following manner.

(a) The head is aligned by placing the test device on its back on a rigid, level surface and by adjusting the head so that it touches the level surface and is laterally centered with respect to the device's axis of symmetry.

(b) The test device is placed in the vehicle in the normal upright sitting posture, and a rigid roller, 6 inches in diameter and 24 inches long, is placed transversely as low as possible against the front of the torso.

(c) The roller is pressed horizontally against the torso with a force of 50 pounds.

(d) Force is applied at the shoulder level to bend the torso forward over the roller, flexing the lower back, and force is then applied to return the test device to the upright sitting posture.

(e) The roller is slowly released.

1.11 Except as otherwise herein specified, the test devices are not restrained during impacts by any means that require occupant action.

1.12 The hands of the test device in the drivers designated seating position are placed within one inch of the steering wheel rim at the horizontal centerline. The right foot is at 90° to the tibia and rests on the undepressed accelerator pedal with the heel resting at the intersection of the accelerator pedal and the floor and the foot positioned on the longitudinal centerline of the pedal. The left leg is placed as in test condition 1.13.

1.13 The hands of each other test device are resting on the seat with the palms touching the legs and the upper arms are resting against the seat back and flush with the body. Where possible, the legs are outstretched with the thighs on the seat and the heels together on the floor with the foot at 90° to the tibia. Otherwise, the tibia are vertical with the feet resting on the floor. The left and right legs of a test device in the center rear designated seating position are in the left and right footwells, respectively.

1.14 A load sensing device is installed in each upper leg so that all force transmitted from the knee to the upper leg is measured.

1.15 Acceleration sensing devices are installed in each test device to measure orthogonal accelerations at the centers of gravity of the head and upper thorax.

1.16 The output of acceleration and load sensing devices is recorded in individual data channels that conform to the requirements of SAE recommended practice J211, October 1970, with channel classes as follows:

(a) Head acceleration -- 1,000 Hz.

(b) Upper thorax acceleration -- 180 Hz.

(c) Upper leg force -- 600 Hz.

(d) Structure -- 60 Hz.

1.17 The sensing devices are rigidly attached to the test devices by mountings that have no resonance frequency within the frequency-range of the specified channel class.

1.18 Instrumentation shall not affect the motion of test devices during impact or rollover.

1.19 The frequency response of all structural crash test instrumentation shall be from 0-300 Hz.

2. Lateral Fixed Pole Crash Test Conditions - The following conditions apply to the lateral crash test.

2.1 A fixed pole approximately 14 inches in diameter shall be used.

2.2 During the entire impact sequence, the pole undergoes no significant amount of dynamic or static deformation, and absorbs no significant portion of the energy resulting from the impact.

3. Rollover Test Conditions - The following conditions apply to the rollover test.

3.1 The test vehicle's brakes are disengaged and the transmission is in neutral.

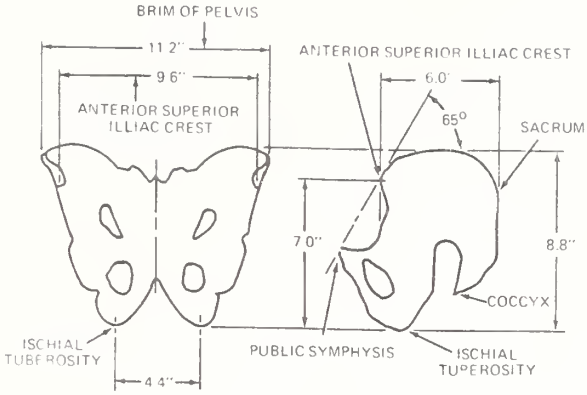
3.2 The surface on which the test is conducted is level, rigid, of uniform construction and of sufficient size that the vehicle remains on it throughout the entire rollover cycle. It has a skid number of 75 when measured in accordance with American Society of Testing and Materials Method E-274-65T at 40 mph omitting water delivery as specified in paragraph 7.1 of that method.

3.3 The vehicle is placed on a device, similar to that illustrated in Figure 2-A, having a platform in the form of a flat, rigid plane at an angle of 23° from the horizontal. At the lower edge of the platform is an unyielding flange, perpendicular to the platform with a height of four inches and a length sufficient to hold in place the thires that rest against it. The intersection of the inner face of the flange with the upper face of the platform is nine inches above the rollover surface. No other restraints are used to hold the vehicle in position during the deceleration of the platform and the departure of the vehicle.

3.4 Before the deceleration pulse, the platform is moving horizontally and perpendicularly to the longitudinal axis of the vehicle at a constant speed of 30 mph for a sufficient period of time for the vehicle to become motionless relative to the platform.

3.5 With the vehicle on the test platform, the test devices remain as nearly as possible in posture specified in test condition 1.

3.6 The platform is decelerated from 30 to 0 mph in a distance of not more than three feet without a change of direction and without transverse or rotational movement during the deceleration of the platform and the departure of the vehicle. The deceleration rate is at least 20g for a minimum of 0.04 seconds.



PELVIC SECTION
50TH PERCENTILE MALE ANTHROPOMORPHIC TEST DEVICE

FIGURE 1

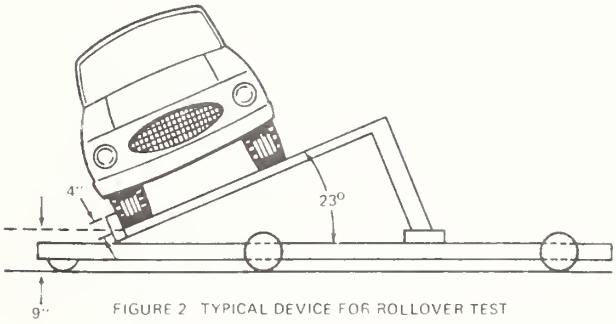


FIGURE 2 TYPICAL DEVICE FOR ROLLOVER TEST

Amendment 1

Technical Specification-

U.S. INTERMEDIATE ESV (RSV)

3.0 VEHICLE SYSTEMS REQUIREMENTS

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3.6 Vehicle Fuel Economy

The RSV shall provide the maximum feasible fuel economy consistent with the priorities of safety and economy and in compliance with the legal requirements for emission controls. Ongoing developments in Federal Energy policy indicate an improvement in overall sales-weighted fleet average fuel economy of 40 percent will be set as a joint Government-Industry goal. Some adjustments are anticipated in emission requirements. The specific apportionment of this improvement goal to the various classes of cars will necessarily be impacted by future market reaction and factors other than vehicle technical changes. Nevertheless, the RSV shall strive to meet a fuel economy performance goal of 30 mpg/(12.75 KM/L) under the following conditions:

ENGINE EMISSIONS: HC - 0.41 gpm

CO - 3.4 gpm

NOX - 2.0 gpm

H_2SO_4 - See NOTE

TEST CYCLE: EPA COMBINED CYCLE

(Ref., Section 2.4, Potential for Motor Vehicle Fuel Economy Improvement - Report to the Congress October 24, 1974)

NOTE: If a H_2SO_4 upper-limit is proposed by EPA for vehicle exhaust, DOT may, at its discretion, adopt this as an emission requirement by contract modification.

This fuel economy goal was derived from:

1. Analyses of 1975 vehicle data in terms of fuel consumption, engine emissions and vehicle performance (i.e., acceleration, passing capabilities, etc.).
2. A vehicle simulation model developed at DOT's Transportation System Center, Cambridge, Mass.

A detail technical report covering the rationale and data used to derive the fuel economy goal is being prepared by NHTSA and will be furnished to all contractors upon completion. The report will discuss in detail the fuel economy, emissions, and vehicle performance tradeoffs required to ensure a fuel efficient yet practical RSV design.

The 30 mpg fuel economy goal shall be considered equal in importance to the 50 mph crashworthiness goal identified in the original government specification for the RSV.

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